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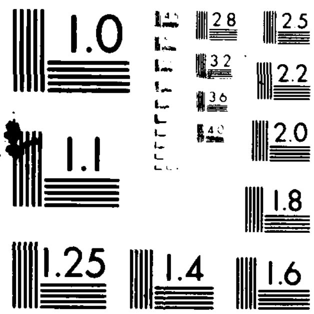

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VOLUME III, PART I

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NUMERICAL AIRCRAFT DESIGN USING 3-D TRANSONIC ANALYSIS
WITH OPTIMIZATION
VOLUME III
PART I. USER"S GUIDE TO TRANSPORT DESIGN COMPUTER PROGRAMS

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BETHPAGE, NEW YORK 11714

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This technical report has been reviewed and is approved for publication.

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This document is the first part of a two part volume of detailed User's Guides for the computer programs ~~produced~~ by Lockheed-Georgia Company and Grumman Aerospace Corp. as ~~part~~ of a new transonic wing design procedure ~~developed under~~ AFWL Contract #F33615-78C-3014. ~~As in the other volumes~~ of this report, Volume 3 is divided into two ~~parts.~~ Part 1 presents the User's Guide for the transport design programs produced by Lockheed-Georgia Company and Part 2 presents the User's Guide for the fighter design programs ~~produced~~ cont

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The purpose of the contract was to develop and validate a new transonic wing design procedure using the numerical optimization technique. The new procedure was used to design both a transport and a fighter configuration. Because the missions and design requirements of a fighter and transport are so different, the design procedure was developed along parallel lines. Lockheed-Georgia Co. developed the transport design procedure, and Grumman Aerospace Corp. developed the fighter design procedure.

Users guides for the computer programs used in the transport design case study for the aircraft design procedure developed as part of the Advanced Transonic Technology (ATT) program are presented. These programs include two 3D transonic wing analysis codes linked to a numerical optimization routine, a two dimensional strip boundary layer program and a wing-pylon-nacelle interference program. The input data required by each program is described in detail. Samples of the output from each program are presented.

PREFACE

This document is the first part of a two part volume of detailed User's Guides for the computer programs produced by Lockheed-Georgia Company and Grumman Aerospace Corp. as part of a new transonic wing design procedure developed under AFWL Contract #F33615-78C-3014. As in the other volumes of this report, Volume 3 is divided into two parts: Part 1 presents the User's Guide for the transport design programs produced by Lockheed-Georgia Company and Part 2 presents the User's Guide for the fighter design programs produced by Grumman Aerospace Corp.

Personnel who contributed to this contract effort are: Lockheed-Georgia Company, A. J. Srokowski, M. E. Lores, R. A. Weed and P. R. Smith; Grumman Aerospace Corp., P. Aidala.

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SECTION I

INTRODUCTION

The transonic wing design procedure (see Fig. 1) described in the previous volumes of this report utilizes the following computer programs: Lockheed's version of the NASA Ames/Bailey-Ballhaus 3A extended small disturbance (ESD) code[1,2] (ATWP), Jameson's FL022 full potential equation (FPE) code[3], Vanderplaat's constrained function minimization (CONMIN)[4,5] code, McNally's 2D boundary layer code (TWODBL)[6], a wing-pylon/nacelle mutual interaction code[7], and viscous linking codes (LINKUP, LINKDN). Both of the inviscid wing analysis codes have been coupled with CONMIN to provide a set of programs that can be used to design and analyze wings that are in some sense optimized for a given set of design conditions and constratins. The boundary layer program, TWODBL, is used to compute displacement thicknesses that are, in turn, used to compute both "fluid" and "hard" wing ordinates during the design process. The wing-pylon/nacelle code is used to evaluate the effects of wing-pylon/nacelle interactions on a design wing pressure distribution. The purpose of this User's Guide is to present the information required to use these programs in the manner specified by the design procedure.

The following sections present general descriptions of the programs and their input requirements, detailed descriptions of input variables and input deck formats, job control requirements and descriptions of program output. In each section, the inputs have been separated, as much as possible, into blocks or modules according to their function. Sample input decks are given to illustrate how these blocks are joined together to form an input deck. Examples of printed output from the programs are presented as well as descriptions of output directed to mass storage for post-run processing. Finally, functional descriptions of each subroutine referenced by the programs and a list of the FORTRAN logical units used by the programs is given as an aid

for future program modifications by the user.

SECTION II

INVISCID ANALYSIS AND DESIGN PROGRAMS

1. GENERAL DESCRIPTION OF THE PROGRAMS

a. Analysis Codes

The two analysis codes used in the transonic wing design procedure described in the previous volumes of this report compute inviscid, irrotational transonic potential flow about 3D wing configurations. The small disturbance code is subject to the following restrictions:

(1) The wing thickness-to-chord ratio is small and the leading edge is not too blunt.

(2) The angle of attack is not too large.

(3) Embedded shock waves are weak ($M < 1.3$).

(4) The boundary layer is negligibly thin.

(5) The wing lies in a plane.

(6) Wing sweep is not excessively large ($\Lambda < 50°$).

The full potential equation code is restricted only by conditions 2, 3 and 4. The salient features of both analysis codes are described in the following sections.

The Ames Bailey-Ballhaus ESD Code (ATWP)

The Bailey-Ballhaus 3A code solves an extended small disturbance approximation of the exact governing equation for potential flow. The partial derivatives in the governing equation are replaced by finite difference approximations that yield a set of nonlinear algebraic equations that are solved by Successive Line Relaxation.

The Bailey-Ballhaus code uses an embedded computational mesh system to accelerate convergence of the relaxation process. This mesh system consists of a wing oriented fine inner mesh embedded in a coarse Cartesian outer mesh. A coordinate transformation is used to map the wing planform into a rectangle in the computational plane. Grid stretching relations are used to

cluster mesh points in the regions around the wing surface where large gradients in the flow variables occur.

The solution process includes alternating sweeps of the crude and fine mesh systems. As a first step, the embedded fine grid is relaxed with the potential function ϕ fixed on the fine grid outer boundary and Neumann boundary conditions imposed on the wing surface. After sweeping the fine mesh, the circulation distribution is computed using fine mesh potentials. The circulation distribution is then used in (1) the far-field expression of Klunker[8], and (2) in the solution of the Laplace equation in the downstream Trefftz plane, to compute the potential on the crude grid outer boundary.

Next, the crude grid is relaxed using the updated potentials on the outer boundaries and Neumann boundary conditions on the airfoil surface. With the crude grid relaxed, the potentials on the fine grid outer boundary are updated (by interpolating the crude grid potentials) and the process repeated until both the crude and fine grid solutions converge.

The Jameson FPE Code (FLO22)

Jameson's FLO22 code solves the full potential equation for inviscid transonic potential flow by finite difference techniques. Unlike the ESD code, the FPE code uses a single computational mesh system. Shearing and square root transformations are used to map the wing surface into a plane in the computational space. The wing surface is, in a sense, "unwrapped" about an arbitrary singular line just inside the leading edge of the profile at each span station. The resulting coordinate system is highly non-orthogonal. The program uses a remeshing scheme to speed up convergence. The program is started with a relatively coarse grid. This grid is relaxed a specified number of iterations. The number of grid lines is then doubled

and the solution is restarted using values from the old grid system interpolated onto the new grid system. This process can be repeated at least two times to achieve the final desired mesh system.

The finite difference approximation of the governing equation utilizes the rotated difference scheme introduced by Jameson which adds a directional bias in the direction parallel to the velocity vector at points where the local flow is supersonic. This scheme helps to alleviate problems induced by the change in equation type (i.e. elliptic to hyperbolic) that occurs when the flow becomes supersonic.

b. Optimization Code

Vanderplaats' CONMIN code is used to perform the optimization of wing sections during the design process. CONMIN is a FORTRAN program, in subroutine form, for the solution of linear or non-linear constrained optimization problems. The user must provide a main program and subroutines to define the optimization problem. Problem definition consists of specification of the quantity to be minimized* (the object function), variables which can be adjusted to attain the minimum (decision variables), and constraints which the solution must satisfy. The basic optimization algorithm used in CONMIN is the Method of Feasible Directions. While the program is intended primarily for efficient solution of constrained problems, unconstrained function minimization may also be solved; the conjugate direction method of Fletcher and Reeves is used for this purpose. The general

*For the purposes of this manual, minimization and optimization are one and the same since CONMIN establishes an optimum by minimizing the user specified object function.

minimization problem is to find the values for the set of variables V(I) (the decision variables) which minimize some object function, OBJ, subject to a set of constraints $G(J) \leq 0$ and a set of upper and lower bounds VUB(I) and VLB(I), respectively, placed on the decision variables.

CONMIN has been coupled with both analysis codes. In the optimization mode, the analysis code is called to generate the pressure distribution used to compute the objective function. CONMIN is called to evaluate the objective function and set the values of the decision variables. These decision variables are used with a set of shape perturbation functions to alter the shape of a desired control station. The analysis code is then executed with the new wing geometry to update the objective function. This cycle is repeated until the objective function is minimized to a desired tolerance.

2. GENERAL DESCRIPTION OF INPUT

The following sections present a general description of the different types of data required by the analysis and optimization programs, the function of specific variables, and the format of different types of data.

In general, the data has been broken into separate blocks according to function. These blocks are then combined in the sequence shown in Figure 2 to form a complete input deck. Each of these blocks will be described separately. In some instances these blocks are broken into smaller sub-blocks which are discussed separately. A detailed definition of each variable is given in the next chapter. Sample data sets are given in Appendix A.

a. Executive Control Flags

Two flags, FESD and FFPE, are used to select which analysis code will be used. The flag, OPTM, is used to select the optimization code. F2DBLS is set when data for use in the TWODBL boundary layer program is to be output.

b. Airfoil Section Input

The section geometry is input by the same routine for both the ESD and the FPE codes. The values of X/C and Z/C for each spanwise control station can be input from cards or from a mass storage file.

Streamwise airfoil sections may be defined at up to 11 arbitrary span stations. A linear variation of coordinates is assumed between the input stations. The first span station must be the wing root and the progression must be monotonic outboard. Input for at least two span stations is required. The flag, AFIN, controls whether the section geometry will be input from cards or mass storage.

Up to 90 ordinates each may be used to define the upper and lower surface of an airfoil. Input coordinates must be normalized by the local chord (X/C,Z/C). In the ESD code, computed airfoil surface slopes may be smoothed KSMTHS times if required.

When inputting the airfoil ordinates at each span station from cards, if the airfoil section is the same as that at the previous span station, a flag, ISAME, is set equal to T and the program automatically uses the previously defined airfoil. If the section at the current span station is different from that at the previous station ISAME is set to F and new ordinates are input. This procedure is followed at each subsequent span station. If the airfoil sections are input from a storage file, the ordinates at every span station must be defined explicitly.

c. ESD Input

The punched card input data for the ESD code are described in this section. Definitions of the input variables and the required input format are presented in Subsection 3.

Program input is divided into five primary blocks: program control, wing planform geometry, mesh skewing control parameters, skewed mesh generation parameters, and Cartesian mesh parameters. These blocks are delineated in Subsection 3 and briefly described below.

Program Control

The control section primarily governs the selection of various program options. Initial conditions, required by the solution technique, are defined by either zeroing the potential function and circulation (IDISK = F), or by reading these data from a previous solution stored on unit 10 (IDISK = T). The latter option can greatly reduce computation time. If initial conditions are to be obtained by interpolating from a coarser mesh solution stored on unit 10, the user sets MSHINT equal to T. Solution data for future restart can be saved on unit 11 by setting ISAVE equal to T.

The program allows the storage of geometric and pressure data for machine plotting. However, machine plotting capability is not currently available with the present system.

Increases in computational efficiency and solution accuracy can be obtained by employing grid embedding and grid refinement. The recommended procedure is to compute a solution on an initial coarse, skewed (wing oriented) mesh, interpolate the results, and resume computing on an embedded grids system. The embedded grids system is composed of a fine interior skewed mesh embedded within a coarse Cartesian exterior mesh.

Two Namelists, FLAG and FLOW, are used to input control parameters and initial conditions. Therefore, only those values that will differ from the specified default values have to be input.

Wing Planform Geometry

A trapezoidal reference wing is defined by parameters YROOT, XLER, XTER, YTIP, XLET, and XTET. The wing reference area, chord, and moment center are defined by SREF, CREF, and XMOM, respectively. All geometric input variables are internally normalized by the root chord of the trapezoidal reference wing: CROOT = XTER - XLER.

The wing leading and trailing edges are defined by (y,x) pairs and end-point slopes (dx/dy). Up to three curved or straight-line segments may be used to define the leading and trailing edges. The input coordinates of each segment are fitted with a cubic spline having imposed first-derivative (dx/dy) end conditions. Only two (y,x) pairs are required to define a straight-line segment. Breaks in planform are permissible, but the leading and trailing edges must be single-valued in y and the tip chord must be finite. YP and THETAP define the spanwise location in fractions of the span and the twist angle of each control section.

Mesh Skewing Control Parameters

This block of input controls the spanwise skewing of the computational mesh. Two curves are defined in the wing reference plane about which the mesh lines are aligned. The curves represent constant values of the transformed coordinate ξ and are defined as the XI = 0 ($\xi = 0$) and XI = 1 ($\xi = 1$) lines. Generally, these curves should coincide with the wing leading and trailing edges in order to give a desirable chordwise distribution of grid points on the wing.

The XI = 0 and XI = 1 curves are described by (y,x) pairs and end-point slopes (dx/dy) in a manner similar to the planform leading and trailing edge description. The same number of segments must be used for the XI = 0 definition as was used for the leading edge description, and similarly for XI = 1 and the trailing edge description. The XI lines must extend spanwise beyond the wing tip to the edge of the computational boundary (ETA_{MAX}), and these curves must not intersect.

Options are included in the program so that the user can allow the XI - curves to coincide with all or some segments of the previously defined planform. Each previously defined segment of the wing leading and trailing edges is examined in turn to test for acceptability as XI - lines. If the leading or trailing edge segment is not a satisfactory definition for the XI - line segment, then (y,x) coordinates are read in for the segment. If the outboard segments of the planform are used for the XI - line description, the spline-fit segments are extrapolated to the spanwise edge of the computational space. If the wing taper ratio is too small or the tip too curved or the outer spanwise boundary located too far outboard, the XI - curve could intersect and cause the program to fail.

Skewed Mesh Parameters

This portion of the input applies to the skewed, wing-oriented grid structure which is either used alone (e.g., as a single coarse, initial mesh) or in conjunction with a crude Cartesian grid (embedded grid structure). As noted in subsection 3 if a solution is to be computed on an initial coarse, skewed mesh and the results interpolated for solution on the embedded grids system (REMESH = T), then parameters for the initial coarse single mesh are input first followed by parameters for the fine mesh of the embedded grid system. The input parameters and input format are essentially the same in

both cases. Namelists GPARM, XGRID, YGRID and ZGRID are used to input mesh control parameters.

The present program has automatic grid generation capability in any or all of the three coordinate directions. If this option is not desired then the appropriate keys are set to T as indicated in Subsection 3. Up to 90 streamwise mesh points (XIN), 30 spanwise mesh points (ETA), and 20 vertical mesh points (ZT) can be input. The coordinate system must be consistent with the planform coordinate system (either dimensional or non-dimensional coordinates).

If the streamwise grid is input, then JMAX values of the mesh coordinates along the centerline must be specified by the user, beginning upstream and proceeding downstream. The mesh should be defined with the largest density of grid points on the wing. The grid spacing should be smallest near the wing leading and trailing edges and should increase smoothly away from the wing. The wing leading edge should be situated midway between grid points.

Input for automatic streamwise grid generation is accomplished via namelist XGRID. All parameters in XGRID have preset (default) values which have been chosen to minimize user input. Only those parameters whose default values are not satisfactory need be input. Two default values for each variable are shown in subsection 3. The first value applies to the initial coarse mesh (if used) and the second to the fine embedded mesh. Parameters XPLE and XPTE control grid stretching at the leading and trailing edges, respectively. If a greater density of grid points is desired at the edges then a smaller value should be used. If automatic grid generation is selected, JMAX is computed internally as NXON + NXFWD + NXAFT. NXON, NXFWD, and NXAFT are the specified number of XI grid lines on, forward, and aft of the wing.

If the spanwise grid is to be read in, then KMAX values must be specified by the user beginning at the wing root (ETA = 0.) and proceeding outboard. Again, the density of grid points should be greatest on the wing, and the grid spacing smallest at the wing root and tip. The tip should be located midway between spanwise grid points. The index of the first grid point outboard of the wing tip (KTIP) must be input.

Some of the above requirements are automatically satisfied when using the spanwise grid generation routine. Namelist YGRID contains the user controlled variables. Grid spacing at the tip is controlled by YPTIP and at the root by ALFP, which is the ratio of wing root-to-tip stretching factors. For a greater density of grid points at the root than at the tip, input ALFP<1.0. KMAX is computed internally as NYON + NYOFF. KTIP is computed as NYON + 1.

Similarly, the vertical coordinates (ZT) at mesh points can be input by the user or generated internally. When read in, LMAX values are given. The wing is positioned vertically in the computational space by specifying LWINGU, the index of the first mesh point above the wing reference plane. The grid density should be greatest near the wing reference plane and should decrease with distance above and below the wing. Namelist ZGRID contains the vertical grid control parameters. When the vertical grid is generated internally, LMAX = ((NZ + 1)/2) X 2 and LWINGU = LMAX/2 + 1.

The parameter MAXIT controls the total number of relaxation sweeps of the grid system. When a solution is being sought for the embedded grids system, MAXIT refers to the total number of *fine* mesh iterations for the current run; i.e., when the number of iterations on the fine mesh equals MAXIT, the run terminates (if convergence is not obtained during the run).

Cartesian Mesh Parameters

Basically, the input procedure for the coarse Cartesian mesh (if required - EXTMSH = T) is identical to that for the skewed mesh, except that now input for controlling mesh skewing is not required (XI - lines). The mesh coordinates can be input by the user or automatic grid generation routines can be called. Namelist names and namelist parameter names (and their definitions) are identical to those for the skewed grid except that an "X" is appended to the names. Namelist GPARM is used for the Cartesian mesh parameters as well as the fine mesh. However, only the parameters appended with "X" must be input.

Parameters MAXITN and MAXITX control the relative proportion of iterations on the fine and crude meshes of the embedded grids system. MAXITN is the number of fine mesh iterations to be computed before computing (or resuming computations) on the coarse mesh. Likewise, MAXITX is the number of coarse mesh iterations to be computed before resuming computations on the fine mesh. The *total* number of iterations on the *fine* mesh is given by MAXIT, which was specified in the previous section.

d. FPE Input

The detailed description of the FPE input is given in Subsection 3. The initial size of the computational grid is specified by FNX, FNY, and FNZ. If the parameter FHALF is not 0, the grid will be doubled after FIT iterations. Card 5 is repeated once for each doubling of the grid. FCONT controls whether the program computes an initial guess or restarts from a stored solution. ZS, XL, YL and CHD are used to define the shape of the planform. XL and YL define the coordinates of the leading edge. Both the leading and trailing edges can have kinks, because the program replaces the leading and

trailing edges as defined by input with a piecewise straight line connecting the nearest mesh points in the computational lattice. Up to 11 span stations can be specified. Card 13 is repeated once for each span station.

e. CONMIN Input

The input required when optimization is selected is described in detail in Subsection 3. The various control parameters and initialization values required by CONMIN are input by the namelist OPTIN. V(I) is the array of decision variables used to perturb the specified design station. The IDV array is used to indicate which of the V values are to be used, i.e.; for IDV = 1,3,5 - V(1), V(3), and V(5) will be used. At the present time, only fifteen decision variables are used. CPD is the array of desired pressure coefficient values that are used to compute the objective function and constraint values. These values should be specified at x/c locations as close as possible to the x/c locations of the spanwise mesh points on the airfoil section being optimized.

Each of the shape functions (see Volume II, Part I, Page 8) used to modify the base airfoil is multiplied by (V(I) - 1.0). Therefore, initializing V(I) = 1.0 "turns off" a shape function until the decision variable, V(I), is changed by CONMIN.

In addition, various types of constraint functions have been incorporated into the ESD and FPE codes. Among these constraints are the desired pressure coefficients mentioned above, specified lift and moment coefficients, and trailing edge thickness. The addition of other constraint functions will require program modifications by the user.

3. DETAILED INPUT VARIABLE DESCRIPTION

In the following sections, the input variables in each of the five blocks of data discussed in the last chapter are defined on a card by card basis. Each block will be treated separately. These blocks are separated by title cards. In most cases, the blocks are broken into sub-blocks by title cards. In the following sections, the input cards are numbered in the sequence they occur in a block or sub-block.

a. Executive Control Flags

The executive control flags are input via the namelist CFLGIN. The default values are given in parenthesis. The control flag inputs are:

1. CFLGIN (NAMELIST INPUT)

FESD	= T selects ESD analysis code (F)
FFPE	= T selects FPE analysis code (F)
OPTM	= T selects CONMIN optimization (F)
F2DBLS	= T signals program to output data to unit 12 for use in TWODBL boundary layer program (F).
K2DBL	= Number of spanwise stations at which data for TWODBL will be output (1).
KOUTBL (I) I = 1, 20	= Integer array containing spanwise indices of stations at which TWODBL data is to be written (20 *2)
KOUT (I) I = 1, 30	= Integer array containing spanwise indices of stations at which pressure distribution data will be printed/plotted on line printer. (30 * 1)

b. Airfoil Section Inputs

Section ordinates can be input from cards (Unit 5) or from mass storage (Unit 8). Input from mass storage assumes values of ordinates have been written for every spanwise station. Mass storage input is compatible with TWODBL program output. The airfoil section inputs are:

1. ATITLE (1 Card, 8A10)

   80 Character Airfoil Section Description

2. AFIN (1 Card, 14L5)

   Logical flag used to indicate that section ordinates are to be read from cards (AFIN = T) or logical Unit 8 (AFIN = F).

3. NPAN,INU,INL,KSMTHS (1 Card, 8I10)

   NPAN = No. of span stations at which airfoil ordinates are input - at least two stations required .LE. 11

   INU = No. of upper surface airfoil ordinates .LE. 90

   INL = No. of lower surface airfoil ordinates .LE. 90

   KSMTHS = No. of times computed surface slopes are smoothed

4. XINU(I),I = 1,INU (INU/8 Cards, 8F10.0)

   X/C at which airfoil upper surface ordinates are input

5. XINL(I),I = 1,INL(INL/8 Cards, 8F10.0)

   X/C at which airfoil lower surface ordinates are input

6. ISAME (1 Card, 14L5)

   ISAME = F to input airfoil ordinates

   = T use previously defined airfoil

7. ZUP(I,N),I=1,INU (INU/8 Cards, 8F10.0)

   Upper surface airfoil ordinates/chord - required if ISAME = F

8. ZLP(I,N),I=1,INL (INL/8 Cards, 8F10.0)

   Lower surface airfoil ordinates/chord - required if ISAME = F

Notes:

A. ISAME must = F for first span station.

B. Repeat cards 6 through 8 NPAN times if AFIN = T.

C. When AFIN - F, cards 4, 5, 7 and 8 are read from Unit 8 with 7 and 8 repeated NPAN times. Card 6 is omitted.

c. ESD Input

The following input is required when the ESD code is selected (FESD = T). The data are broken into sub-blocks in the order that they are input.

ESD Control Flags:

1. TITLE (1 Card, 8A10)

   80 Character Problem Title

2. FLOW (Namelist input, default values are in parenthesis)

   MACHNO = Free stream Mach number (.8)

   ALPHAW = Wing reference plane angle of attack, degrees (0.0)

   GAMMA = Specific heat ratio (1.4)

   RFACT = Regiels rule factor for modified slopes (.01)

   EMEXP(1) = Mach No. exponent in nonlinear term
   = 2.0 for Von Karman-Spreiter scaling
   = 1.75 for modified Krupp scaling (1.75)

   EMEXP(2) = Mach No. exponent in wing B. C.
   = 1.0 for Von Karman-Spreiter scaling
   = -.25 for modified Krupp scaling (-.25)

3. FLAG (Namelist input, default values are in parenthesis)

   IDISK = T start from old solution stored on Unit 10 (F)

   MSHINT = T initial conditions interpolated from old coarser (F) mesh solution. IDISK must be true if MSHINT is true.

ISAVE = T to save data for future restart - written on Unit 11 (T)

IPLOT = T to save data for plotting - written on Unit 14 (F)

SOLV = T for complete execution. Otherwise, stop before solve loop is entered (T).

WBCPRT = T to output wing surface slopes. (F)

FCR = T for fully conservative method (T).

ISPAN = T for inclusion of extra spanwise terms in equation (T).

EXTMSH = T to input both fine interior mesh and coarse exterior mesh (T).

= F to compute with fine interior mesh alone

REMESH = T to compute solution on initial mesh, interpolate, and resume computing on embedded grids system

= F to omit solution on initial mesh (T).

Planform Geometry:

1. PTITLE (1 Card, 8A10)

   80 Character wing planform description

2. YROOT,XLER,XTER,YTIP,XLET,XTET,SREF,CREF,XMON (2 Cards, 6F10.0)

   These variables define trapezoidal reference wing

   YROOT = Y coordinate of root

   XLER = X coordinate of L.E. at root

   XTER = X coordinate of T.E. at root

   YTIP = Y coordinate of tip

   XLET = X coordinate of L.E. at tip

   XTET = X coordinate of T.E. at tip

   SREF = Wing reference area

CREF = Reference chord

XMON = Moment reference

3. NLES (1 Card, 8I10)

NLES - No. of segments input to describe the leading edge

NLES.LE.3

4. NLEI (1 Card, 8I10)

NLEI = No. of Y,X pairs defining leading edge segment NLEI.LE.10

5. YLEI(I),XLEI(I),I=1,NLEI (NLEI/4 Cards, 8F10.0)

YLEI,XLEI = Y,X pairs defining the leading edge segment

At least two pairs required

Same dimensional system as XLER, etc.

6. DXLER,DXLET (1 Card, 8F10.0)

DXLER = DX/DY of L.E. at inboard edge of setment

DXLET = DX/DY of L.E. at outboard edge of segment

Note: Repeat cards 4 thru 6 NLES times

7. NTES (1 Card, 8I10)

NTES = No. of segments input to describe the trailing edge

NTES.LE.3

8. NTEI (1 Card, 8I10)

NTEI = No. of Y,X pairs defining trailing edge segment

NTEI.LE.10

9. YTEI(I),XTEI(I),I=1,NTEI (NTEI/4 Cards, 8F10.0)

YTEI,XTEI = Y,X pairs defining the trailing edge segment

At least two pairs required

10. DXTER,DXTET (1 Card, 8F10.0)

DXTER = DX/DY of T.E. at inboard edge of segment

DXTET = DX/DY of T.E. at outboard edge of segment

NOTE: Repeat cards 8 thru 10 NTES times

11. YP(N),THETP(N),N=1,NPAN (NPAN/4 Cards, 8F10.0)

YP = Fraction of semispan at which airfoils are defined

THETP = Twist Angle, degrees, at YP - Positive is L.E. up

Mesh Skewing Parameters:

1. STITLE (1 Card, 8A10)

80 Character description of skewed mesh parameters

2. NSO (1 Card, 8F10.0)

NSO = No. of segments defining XI = 0 line

3. XORD(I),I=1,NSO (1 Card, 14L5)

XORD(I) = T Read in XI=0 line for Segment I

= F XI=0 line for Segment I same as wing L.E. Seg. I

NOTE: If XORD(I) = F, skip cards 4 to 6 for Segment I

4. NXO (1 Card, 8I10)

NXO = No. of Y,X pairs defining segment (NXO.LE.10)

5. YXO(I),XXO(I), L=1,NXO (NXO/4 cards, 8F10.0)

YXO,XXO = Y,X pairs defining segment

6. DXRO,DXTO (1 Card, 8F10.0)

DXRO = DX/DY at inboard edge

DXTO = DX/DY at outboard edge

NOTE: Repeat cards 4 thru 6 for each XORD(I)=T

7. NTIPLE,NTIPXI (1 Card, 8I10)

Input NTIPLE,NTIPXI = 0

8. NSI (1 Card, 8I10)

NSI = No. of segments defining XI = 1 line

9. XIRD(I),I=1,NSI (1 Card, 14L5)

XIRD(I) = T Read in XI=1 line for Segment I

= F XI=1 line for Segment I same as wing T.E. Seg. 1

NOTE: If XIRD(I) = F, skip Cards 10 - 12 for Segment 1

10. NXI (1 Card, 8I10)

NXI = No. of Y,X pairs defining segment (NXI.LE.10)

11. YXI(I),XXI(I),I=1,NYI (NXI/4 Cards, 8F10.0)

YXI,XXI = Y,X pairs defining segment

12. DXRI,DXTI (1 Card, 8F10.0)

DXRI = DX/DY at inboard edge

DXTI = DX/DY at outboard edge

NOTE: Repeat cards 10 - 12 for each XIRD(I)=T

<u>Mesh Parameters for Fine Interior Mesh (and Initial Coarse Mesh if REMESH = T):</u>

NOTE: If REMESH = T, follow steps A and B

If REMESH = F, do step C

A. Input initial coarse single mesh using Cards 1 - 11

B. Repeat Cards 1 - 11 for fine mesh

C. Input Cards 1 - 11 for fine mesh

1. TITLEM (1 Card, 8A10)

80 Character mesh description

2. GPARM (Namelist input, default values in parenthesis)

MAXIT = No. of iterations for current run (200)

INCR = Iteration increment between write of residual data (1)

RSUB = Subsonic relaxation parameter (1.8)

RTEST = Convergence criterion of maximum potential error (.001)

EPS = Coefficient of PXT (1.)

KMAX = Number of spanwise (ETA) mesh points (0)*

JMAX = Number of streamwise (XI) mesh points (0)*

LMAX = Number of vertical (ZT) mesh points (0)*

KTIP = First mesh point beyond wing tip (0)*

LWINGU = ZT mesh index of first point above wing plane (0)*

XMRD = T read in XIN mesh, = F compute XIN mesh (F)

YMRD = T read in ETA MESH, = F compute ETA mesh (F)

ZMRD = T read in ZT mesh, = F compute ZT mesh (F)

NOTE: If XMRD = T, skip Card 3, If XMRD = F, skip Cards 4,5

3. XGRID (Namelist input, default values in ( ), first no. applies to initial coarse mesh, second no. to fine interior mesh)

NXAFT = No. of streamwise mesh points behind wing (5,7)

NXON = No. of streamwise mesh points ahead of wing (8/10)

NXFWD = No. of streamwise mesh points ahead of wing (8/10)

ALPXF = Dist. from L.E. to upstream bdy. In root chords (3./.5)

ALPXA = Dist. from T.E. to downstream bdy. In root chords (4./.5)

ALF = Location of wing T.E. between grid lines. If ALF=0, TE on grid line. ALF=.5, midway between, etc. (0./0.)

XPLE = Grid stretching factor at wing

XPTE = Grid stretching factor at wing T.E. (.2/.2)

4. XIN(J),J=1,JMAX (JMAX/8 Cards, 8F10.0)

XIN = X mesh along centerline

5. RX (1 Card, 8F10.0)

RX = Scale factor for XIN mesh (XIN = XIN*RX)

*Values for these parameters are computed internally when XMRD, YMRD, and ZMRD = F.

NOTE: If YMRD = T, skip Card 6

If YMRD = F, skip Cards 7,8

6. YGRID (Namelist input, default values in ( ), first no. applies to initial coarse mesh, second no. to fine interior mesh)

NYON = No. of spanwise mesh points on wing (9/25)

NYOFF = No. of spanwise mesh points off wing (3/5)

ALPY = Y dist. from wing tip to ETA bdy. In semi-spans (.5/.25)

YPTIP = Grid stretching factor at wing tip (.5/.5)

ALEP = Ratio of wing root-to-wing tip stretch factor (1./1.)

7. ETA(K),K=1,KMAX (KMAX/8 Cards, 8F10.0)

ETA = Spanwise coordinate at mesh points

8. RY (1 Card, 8F10.0)

RY = Scale factor for ETA mesh (ETA = ETA*RY)

NOTE: If ZMRD = T, skip Card 9

If ZMRD = F, skip Cards 10, 11.

9. ZGRID (Namelist input, default values in ( ), first no. applies to initial coarse mesh, second no. to fine interior mesh)

NZ = No. of vertical mesh points, even (16/20)

ALPZ = Location of outer ZT boundary in root chords (3./2.)

ZP = Grid stretching factor at ZT=0. (.2/.2)

10. ZT(L),L=1,LMAX (LMAX/8 Cards, 8F10.0)

ZT = Vertical coordinate at mesh points

11. RZ (1 Card, 8F10.0)

RZ = Scale factor for ZT mesh (ZT = ZT*RZ)

Parameters for Use with Coarse Exterior Mesh:

NOTE: If EXTMSH = F, skip Cards 1 - 11

(Compute with only one mesh)

1. TITLEM (1 Card, 8A10)

80 Character Coarse Exterior Mesh Description

2. GPARM (Namelist input, default values in parenthesis)

MAXITN = Number of iterations on fine mesh before computing on outer mesh (1)

MAXITX = Number of iterations on coarse mesh before returning to fine mesh (1)

INCRX = Print increment for coarse mesh iterations (1)

RSUBX = Subsonic relaxation parameter for coarse mesh (1.8)

EPSEX = Coefficient of RXT in coarse mesh calculation (.5)

JMAXX = Number of streamwise (XINX) mesh points* (0)

KMAXX = Number of spanwise (ETAX) mesh points* (0)

LMAXX = Number of vertical (ZTX) mesh points* (0)

KTIPX = First ETAX mesh point beyond wing tip* (0)

LWNGUX = ZTX mesh index of first point above wing plane * (0)

XMRDX = T read in XINX mesh, = F compute XINX mesh (F)

YMRDX = T read in ETAX mesh, = F compute ETAX mesh (F)

ZMRDX = T read in ZTX mesh, = F compute ZTX mesh (F)

NOTE: If XMRDX = T, skip Card 3, If XMRDX = F, skip Cards 4,5

3. XGRIDX (Namelist input, default values in parentheses)

NXONX =		(14)
NXFWDX =	See	(8)
NXAFTX =	Description	
ALPXFX =	for	(5.)

* Values for these parameters are computed internally for XMRDX, YMRDX, and ZMRDX = F.

ALPXAX	=	Card 3	(5.)
ALFX	=	Previous	(0.)
XPLEX	=	Section	(1.)
XPTEX	=		(.5)

4. XINX(J),J=1, JMAXX (JMAXX/8 Cards, 8F10.0)

   XINX = Streamwise coordinate at mesh points

5. RX (1 Card, 8F10.0)

   RX = Scale factor for XINX mesh

NOTE: If YMRDX = T, skip card 6

If YMRDX = F, skip Cards 7,8

6. YGRIDX (Namelist input, default values in parentheses)

NYONX	=	See	(10)
NYOFFX	=	Description	(5)
ALPYX	=	Card 6	(1.)
YPTIPX	=	Previous	(.5)
ALFPX	=	Section	(1.)

7. ETAX(K),K=1,KMAXX (KMAXX/8 Cards, 8F10.0)

   ETAX = Spanwise coordinate at mesh points

8. RY (1 Card, 8F10.0)

   RY = Scale factor for ETAX mesh

NOTE: If ZMRDX = T, skip Card 9

If ZMRDX = F, skip Cards 10,11

9. ZGRIDX (Namelist input, default values in parentheses)

NZX	=	See Card 9	(20)
ALPZX	=	Previous	(5.)
ZPX	=	Section	(.5)

10. ZTX(L),L=1,LMAXX (LMAXX/8 Cards, 8F10.0)

ZTX = Vertical coordinate at mesh points

11. RZ (1 Card, 8F10.0)

RZ = Scale factor for ZTX mesh.

d. FPE Input

The following data are required by the FPE code. Separate cards or groups of cards are separated by a title card which may be blank.

1. TITLE (1 Card, 8A10)

TEST CASE TITLE

2. Data title card

3. FNX, FNY, FNZ, FPLOT, XSCAL, PSCAL, FCONT, FPRINT (1 Card, 8F10.0)

FNX — The number of mesh cells in the direction of the chord used at the start of the calculation.

FNX = 0 causes termination of the program.

FNY — The number of mesh cells in the direction normal to the chord and span.

FNZ — The number of mesh cells in the span direction.

FPLOT — Controls generation of plots.

FPLOT=0. for a print plot but no Calcomp plot at each span station.

FPLOT=1. for both print plot and a Calcomp plot at each span station.

FPLOT=2. for a Calcomp plot but no print plot at each span station.

FPLOT=3. for a three dimensional Calcomp plot only.

XSCAL, PSCAL — Control the scales of the Calcomp plots.

XSCAL>0. scales each section plot to XSCAL

XSCAL=0. scales each section plot to 5.0

XSCAL<0. scales the maximum chord to XSCAL, and each section plot proportionately to the local chord.

PSCAL≠0. sets the pressure scale to PSCAL per inch in each section plot. Also,

PSCAL≥0. scales the three dimensional plot so that the span or semispan is 5. If PSCAL=0. and XSCAL≠0. then the three dimensional plot is scaled so that the maximum chord is 1/2 XSCAL.

FCONT Indicator which determines the manner of starting the program.

FCONT≤1. indicates the calculation begins at iteration zero. Restart solution stored when FCONT=1.

FCONT=2. indicates the computation is to be continued from a previous calculation. In this case the values of the velocity potential and the circulation are read from a mass storage file where they were previously stored (Tape 4). It is still necessary to provide the complete data deck to redefine the geometry. The count of the iteration cycles is continued from the final count of the previous calculation and the maximum number of additional iterations to be performed is defined by FIT.

FPRINT FL022 print control flag

FPRINT=0 prints final mesh only

FPRINT≠0 prints every mesh

4. Data Title Card

5. FIT, COVO, P10, P20, P30, BETAO, STRIPO, FHALF (1 to 3 cards, (8F10.0)

FIT The maximum number of iteration cycles which will be computed.

COVO The desired accuracy. If the maximum correction is less than COVO the calculation terminates or proceeds to a finer mesh, otherwise, the number of cycles set by FIT are completed.

P10 The subsonic relaxation factor for the velocity potential. It is between 1. and 2. and should be increased towards 2. as the mesh is refined.

P20 The supersonic relaxation factor for the velocity potential. It is not greater than 1. and is normally set to 1.

P30 The relaxation factor for the circulation. It is usually set to 1., but can be increased.

BETA0 The damping parameter controlling the amount of added ϕ_{st}. It is normally set between 0. and 0.25.

STRIP0 Determines the split between horizontal and vertical line relaxation and is the proportion of the total mesh in which horizontal line relaxation is used. Fastest convergence is usually obtained by setting STRIP0 = 1. so that horizontal line relaxation is used for the entire mesh. If convergence difficulties are encountered STRIP0 may be reduced to some fraction between 0. and 1.

FHALF Determines whether the mesh will be refined. FHALF=0.: the computation terminates after completing the prescribed number of iteration cycles or after convergence.

FHALF≠0: the mesh spacing will be halved after FIT iterations have been run on the crude mesh size.

Card 5 is repeated if FHALF is not 0.

FHALF<0: the interpolated potential will be smoothed (FHALF) times.

6. Data Title Card

7. FMACH, YA, AL, CDO, PWR, RUN (1 Card, 8 F10.0)

FMACH The free stream Mach number.

YA The yaw angle of the wing in degrees.

AL The angle of attack in degrees. When the wing is yawed, AL is measured in the plane normal to the leading edge, not in the free stream direction.

CDO The estimated parasite drag due to skin friction and separation. It is added to the pressure drag (sum of vortex drag plus wave drag) calculated by the program to give the total drag.

PWR Exponent of THICK parameter used to scale computed values of XSING and YSING.

RUN Flag used to control whether a complete FPE run is to be executed.

= 0., Generate mesh only

= 1., Execute complete run

8. Data Title Card

9. ZSYM, SWEEP1, SWEEP2, SWEEP, DIHED1, DIHED2, DIHED (1 card, 8F10.0)

ZSYM Determines whether to treat a wing on a wall or an isolated wing.

ZSYM=1.: the wing is on a wall

ZSYM=0.: the wing is an isolated wing at a yaw angle given by YAW.

SWEEP1 Sweep of singular line at the wing root if ZSYM=1., or at the leading tip if ZSYM=0.

SWEEP2 Sweep of singular line at the tip. (SWEEP1 and SWEEP2 are used as end conditions for spline fitting the x coordinates of the singular line.)

SWEEP Sweep of singular line in the far field.

DIHED1 Dihedral of singular line at the wing root if ZSYM=1., or at the leading tip if ZSYM=0.

DIHED2 Dihedral of singular line at the tip. (DIHED1 and DIHED2 are used as end conditions for spline fitting the y coordinates of the singular line.)

DIHED Dihedral of singular line in the far field.

10. Data Title Card

11. SR, CR, XR, BO2 (1 card, 8F10.0). (Units must be consistent with Card 13)

SR Reference wing area

CR Reference chord length

XR Moment reference length

BO2 Semi span length

12. Data Title Card

13. ZS, XL, YL, CHD, THICK, AL (NPAN cards, 8F10.0)

ZS Span location of the section.

XL,YL x and y coordinates of the leading edge.

CHD The local chord value by which the profile coordinates are scaled.

THICK Modifies the section thickness. The y coordinates

are multiplied by THICK.

AL The angle through which the section is rotated to introduce twist. In the case of a yawed wing, this angle is measured in the axis system attached to the wing, not in the direction of the free stream.

Note: Card 13 is repeated once for each span station.

e. CONMIN Input

The following inputs are required when optimization is selected (OPTM=T):

1. Data Title Card

2. OPTIN (Namelist Input, default values are in parenthesis)

NPRINT (5) Print Control. All printing is done on file number 6.

= 0 Print nothing.

= 1 Print initial and final function information.

= 2 Print all of above plus control parameters. Print function value and V-vector at each iteration.

= 3 Print all of above plus all constraint values, numbers of active or violated constraints, direction vectors, move parameters and miscellaneous information. The constraint parameter, BETA, printed under this option approaches zero as the optimum objective is achieved.

= 4 Print all of the above plus gradients of objective function, active or violated constraint functions and miscellaneous information.

= 5 Print all of the above plus each proposed design during the 1-dimensional search.

NV (0) Number of decision variables, V(I), contained in vector V.

ITMAX (1) Maximum number of iterations in the minimization process. If NFDG = 0, each iteration requires one set of gradient computations (INFO = 3 or 4) and approximately three function evaluations (INFO = 1 or 2). If NFDG≠0, each iteration requires approximately NV + 3 function evaluations (INFO = 1 or 2).

NCON (0) Number of constraint functions, G(J). NCON may be zero.

NSIDE (1) Side constraint parameter.

= 0 The variables V(I) do not have lower or upper bounds.

≠ 0 All variables V(I) have lower and upper bounds defined by VLB(I) and VUB(I), respectively. If any variables are not bounded while others are, the values of the lower and upper bounds on the unbounded variables must be taken as very large negative and positive values, respectively. (i.e. VLB (I) = -1.E+10, VUB (I) = 1.E+10)

ICNDIR (NV + 1) Conjugate direction restart parameter. If the function is currently unconstrained, (all G(J)<CT or NCON and NSIDE = 0), Fletcher-Reeves conjugate direction method will be restarted with a steepest descent direction every ICNDIR iterations. If ICNDIR = 1, only steepest descent will be used.

NSCAL	(3)	Scaling control parameter. The decision variables will be scaled linearly.
	< 0	Scale variables V(I) by dividing by SSCAL(I), where vector SSCAL(I) is defined by user.
	= 0	Do not scale the variables.
	> 0	Scale the variables every NSCAL iterations. Variables are normalized so that the scaled V(I) = V(I)/|V(I)|. When using this option it is desirable that NSCAL = ICNDIR if ICNDIR is input as nonzero, and NSCAL = NV + 1 if INCDIR is input as zero.
NFDG	(1)	Gradient calculation control parameter.
	= 0	All gradient information is provided by an external subroutine. This information may be calculated analytically, or by finite difference, at the user's discretion.
	= 1	All gradient information will be calculated by finite difference in CONMIN. External subroutine provides only function values, OBJ and G(J), J = 1, NCON.
	= 2	Gradient objective function is provided by an external subroutine and gradients of active and violated constraints are calculated by finite difference in CONMIN. This option is desirable if the gradient of the objective function is easily obtained in closed form, but gradients of constraint functions, G(J), are unobtainable. This option may improve efficiency if several variables are limited by lower or upper bounds.

FDCH (0.) Not used if NFDG = 0. Relative change in dec'sion variable V(I) in calculating finite difference gradients. For example, FDCH = .01 corresponds to a finite difference step of one percent of the value of the decision variable.

FDCHM (0.) Not used if NFDG = 0. Minimum absolute step in finite difference gradient calculations. FDCHM applies to the unscaled variable values.

CT (-.05) Constraint thickness parameter.

If CT $\leq$ G(J) $\leq$ |CT|, G(J) is defined as active. If G(J) > |CT|, G(J) is said to be violated. If G(J)> |CT| G(J) is not active, CT is sequentially reduced in magnitude during the optimization process. If |CT| is very small, one or more constraints may be active on one iteration and inactive on the next, only to become active again on a subsequent iteration. This is referred to as "zig-zagging" between constraints. A wide initial value of the constraint thickness is desirable for highly non-linear problems to reduce the zig-zagging problem.

CTMIN (0.) Minimum absolute value of CT considered in the optimization process. CTMIN may be considered as 'numerical zero', since it may not be meaningful to compare numbers smaller than CTMIN. The value of CTMIN is chosen to indicate that satisfaction of a constraint is acceptable.

CTL (-.001) Constraint thickness parameter for linear and side constraints. CTL is smaller than CT because the zig-zagging problem is avoided with linear and side constraints.

CTLMIN (.0005) Minimum absolute value of CTL considered in the optimization process.

THETA (1.) Mean value of the push-off factor in the method of feasible directions. THETA is called a push-off factor because it pushes the design away from the active constraints into the feasible region. A larger value of THETA is desirable if the constraints, G(J), are known to be highly non-linear and a smaller value may be used if all the constraints are known to be nearly linear. The actual value of the push-off factor used in the program is a quadratic function of each G(J), varying from 0. for G(J) = CT to 4. * THETA for G(J) = |CT|. A value of THETA = 0. is used in the program for constraints which are identified by the user to be strictly linear.

PHI (0.) Participation coefficient, used if a design is infeasible (one of more G(J) > |CT|). PHI is a measure of how hard the design will be 'pushed' towards a feasible region and is, in effect, a penalty parameter. If, in a given problem, a feasible solution cannot be obtained with the default value, PHI should be increased and the

problem run again. If a feasible solution cannot be obtained with PHI = 100., it is probable that no feasible solution exists.

DELFUN (0.) Minimum relative change in the object function to indicate convergence. If in ITRM consecutive iterations, $|1. - OBJ(J-1) / OBJ(J)| < DELFUN$ and the current design is feasible (all $G(J) \leq |CT|$), the minimization process is terminated. If the current design is infeasible, (some $G(J) > |CT|$), five iterations are required to terminate and this situation indicates that a feasible design may not exist.

DABFUN (0.) Same as DELFUN except comparison is on absolute change in the object function, $|OBJ(J) - OBJ(J-1)|$, instead of relative change.

LINOBJ (0) Linear objective function identifier.

= 1 The objective (OBJ) is specifically known to be a strictly linear function of the decision variables, V(I).

= 0 The objective is a general non-linear function.

ITRM (1) Number of consecutive iterations to indicate convergence by relative or absolute changes (DELFUN or DABFUN).

VLB(I) I=1,20 Not used if NSIDE = 0. VLB(I) is the lower allowable value (lower bound) of variable V(I). If one or more variables, V(I), do not have lower bounds, the corresponding VLB(I) must be initialized to a very large negative number (i.e. -1.E+10).

VUB(I) I=1,20 — Not used if NSIDE = 0. VUB(I) is the maximum allowable value (upper bound) of variable V(I). If one or more variables, V(I), do not have upper bounds, the corresponding VUB(I) must be initialized to a very large positive number (i.e. 1.E+10).

SSCAL(I) I=1, 20 — Not used if NSCAL = 0. Vector of scaling parameters. The decision of if, and how, the variables should be scaled is highly problem dependent, and some experimentation is desirable for any given class of problems. Efficiency of the optimization process can sometimes be improved if the variables are either normalized or scaled in such a way that the partial derivative of the object function (OBJ) with respect to variable V(I) is of the same order of magnitude for all V(I). SSCAL(I) must be greater than zero because a negative value of SSCAL(I) will result in a change of sign of V(I) and possibly yield erroneous optimization results.

If NSCAL>0, vector SSCAL need not be initialized since SSCAL will be defined in CONMIN and its associated routines.

If NSCAL<0, vector SSCAL is initialized in the main program, and the scaled variables V(I) = V(I)/SSCAL(I).

ISC(I) I=1, 20 — Not used if NCON = 0. Linear constraint identification vector.

If constraint G(J) is known to be linear function of the decision variables V(I), ISC(J) should be initialized to ISC(J) = 1. Identification of linear constraints may improve efficiency of the optimization process and is therefore desirable, but not essential.

If constraint G(J) is non-linear, ISC(J) is initialized to ISC(J) = 0. If G(J) is not specifically known to be linear, set ISC(J) = 0.

ALPCON	(.02)	Controls initial step size in 1-dimensional search.
BICON	(4.)	Controls subsequent 1-dimensional search step size.
ALPHAX		Limit of change in decision variable.
ABOBJ1		Limit of change in OBJ function.
ICONCP	= 1	Selects C_p constraints.
ICONCL	= 1	Selects wing C_L constraint.
ICONCM	= 1	Selects wing C_M constraints.
ICNTHK	= 1	Selects trailing edge thickness constraint
CLDSN		Design C_L for ICONCL = 1.
CMDSN		Design C_M for ICONCM = 1.
OBJCON	(.1)	Scale factor for calculation of OBJ function.

3. Data Title Card

4. KSD, KSURF, KCP, ILE, ITE, NCP1, NCP2, NVT (1 Card, 8I10)

KSD	Control Station being designed
KSURF	= 1, upper surface is perturbed
	= 2, lower surface is perturbed
KCP	Spanwise grid index at which design C_p values are compared with computed values

ILE Initial chordwise grid index of range of C_p values used to compute ΔC_p constraints.

ITE final chordwise grid index of range of C_p values used to compute C_p constraints.

NCP1 Initial chordwise grid index of range of C_p values used to compute objective function.

NCP2 Final chordwise grid index of range of C_p values used to compute objective function.

NVT Number of decision variables V(I) to be input.

Note: In the ESD code, the upper and lower surfaces have the same chordwise indices. For the FPE code, the upper and lower surfaces have different indices.

5. Data Title Card

6. V(I) (NVT/8 cards, 8F10.0)

   Decision variable array. Setting V(I) = 1 will prevent a decision variable from being used until changed by CONMIN

7. Data Title Card

8. IDV (NV/8 cards, 8I10)

   Decision variable index array. Used to specify which of the V(I) values input will be used to turn on or off the corresponding shape functions.

9. Data Title Card

10. CPD ((ITE-ILE)/8 cards, 8F10.0)

    Array of design C_p values; up to 120 values can be input

11. Data Title Card

12. ZTEMIN, ZTEMAX (1 card, 8F10.0)

    Minimum and maximum trailing edge thickness constraints.

4. DESCRIPTION OF OUTPUT

The ESD and the FPE codes generate printed output and output written to mass storage or tape. The CALCOMP plot routines from the original FLO22 program have been retained in the FPE code. The ESD code writes pressure distribution data that can be used for post run plotting to logical unit. Both the ESD and the FPE codes can store data for restart purposes and for the TWODBL boundary layer program. The following sections describe the output that is printed and stored by both the ESD and the FPE codes.

a. ESD Output

An abbreviated example of a typical ESD run with CONMIN is given in Appendix B. The output from a normal ESD run can be broken into six major sections. These sections are

Section I -- Input Parameters

This section of output is simply a listing of all of the input variables.

Section II -- Computational Grid

Information concerning the computational grid structure (skewed or Cartesian grid) are listed here. This includes the distribution of grid points in each of the three coordinate directions and, for the skewed grid, the upstream and downstream boundary locations as a function of span. The listed grid coordinates are normalized by the planform root chord, CROOT. ETA and ZT are physical normalized coordinates (y,z) but XI is the transformed computational coordinate, ξ, along the centerline (ETA=0).

Section III -- Wing Planform Data

This section gives data describing the geometry of the wing planform and the location of the wing within the computational mesh. Also presented are the streamwise ordinates of the XI = 0 and XI = 1 skewlines at each ETA grid station.

Section IV -- Wing Surface Geometry

The next section of output gives the local wing chord and twist angle, and wing surface ordinates and slopes at each ETA span station. This section of output can be suppressed by setting WBCPRT equal to F in the input.

Section V - Relaxation History

This section presents a history of the relaxation process. The magnitude and location of the largest change in the potential function on both the fine and coarse grids are given. The change in potential on the downstream boundary, the lift due to circulation and the number of supersonic points are also given.

Section VI -- Pressure and Force Results

Wing surface pressures, the corresponding local Mach numbers, and sonic-line coordinates are listed at each span station. These pressure distributions are integrated chordwise using Simpson's rule to give section force and moment coefficients and spanwise loadings. Total wing force and moment coefficients are then computed by integrating the section data spanwise. These are normalized by the input reference wing area and chord. Also shown is the total lift coefficient computed from the wing circulation distribution, $\Gamma(y)$. The circulation lift is usually slightly larger than the integrated lift because of "pressure leakage" near the wing leading edge.

When a solution is first computed on an initial coarse mesh (REMESH=T), the above sections of output are listed first for the initial solution, then repeated for the solution on the final mesh. Also, when the final mesh consists of a fine skewed grid embedded within a crude Cartesian outer grid (EXTMSH=T), output section II and III are presented for both grids of the embedded grids system.

When CONMIN is cycled with the ESD code, additional output is generated. This output includes the current values of the objective function, the design variable array, the modified upper and lower surface ordinates of the design station and the twist angle at each control station. The force data described in section VI is printed after the final optimization cycle is executed.

Whenever IPLOT = T, the ESD programs will write data to unit 14 for use in a user supplied plotting program. The following cards are required to read the data from mass storage.

```
      READ (14) KTM1, (ETA(K), K=1,KTM1), (JLE(K), K=1, KTM1), (JTE(K),
      K=1, KTM1)
      DO10 K=1, KTM1
      JL = JLE(K)
      JT = JTE(K)
      READ (14) (CPU(K,J), J = JL,JT)
      READ (14) (CPL(K,J), J = JL,JT)
      READ (14) (XOC(K,J), J = JL,JT)
   10 CONTINUE
```

where

KTM1 = No. of spanwise grid stations minus one

ETA = Spanwise coordinate

JLE = Chordwise grid index of leading edge

JTE = Chordwise grid index of trailing edge

CPU = Upper surface pressure coefficient

CPL = Lower surface pressure coefficient

XOC = X/C values at each span station

b. FPE Output

The FPE code generates printed output that is similar to the output from the ESD code. An example of this output is given in Appendix B. The first block of data that is printed is the reference values of the wing area, semispan, mean chord, sweep and dihedral that are input into the program. This block is followed by the computed x and y coordinates of the singular line of the square root coordinate transformation at each spanwise control station.

If optimization is not selected, the next data printed describes the computational mesh system being used. The coordinates of the unfolded sections produced by the square-root transformation at the root and tip are printed and plotted. This data is followed by the normal and spanwise cell distributions in the square root plane and the coordinates of the singular line at the spanwise grid stations. If mesh halving is being used, these blocks of data are printed for only the final mesh system.

The next major block of data displayed is the iteration history. The maximum correction to the velocity potential, the maximum residual of the difference equations, the circulation at the wing centerline and the number of supersonic points are printed at the end of each cycle for each mesh system used in the run.

When a convergence criterion has been satisfied or a specified number of iterations has been completed, the program prints the section lift, drag, and moment coefficients at specified span stations. The pressure distribution is printed and plotted at equal intervals in the mapped plane. The final blocks of data present the force and moment coefficients for the entire wing.

The print generated when optimization is selected is essentially the same as in the ESD code. The values of the objective function, the decision variables, and the ordinates of the span station being optimized are given.

The FPE code can also generate CALCOMP plots of the pressure distribution at each span station or a plot of the three-dimensional pressure distribution over the upper and lower surfaces separately.

5. JOB CONTROL REQUIREMENTS

a. Job Control Cards

The programs described in this user's guide have executed on two CDC computers, the 7600 under the SCOPE operating system and the CYBER 176 under the NOS operating system. The job control information required to run the programs on the CYBER 176 under the NOS system is presented in this section.

The FORTRAN code that makes up the ESD, FPE and CONMIN programs is stored in three separate permanent mass storage files in UPDATE program library format. The user can therefore compile these three separate blocks of code into binary decks that can be linked together in the manner desired by the user. The following examples illustrate the various ways the ESD and FPE codes can be executed with or without CONMIN.

Sample decks

1. Compile And Execute ESD or FPE From Update File

```
JOB card
USER card
CHARGE card
CALL, FTN176
ATTACH (OLDPL=ESDCON)
          or
ATTACH (OLDPL=FPECON)
UPDATE (F)
FTN (I,LCM=I,L=0)
RFL (EC=440)
LDSET (PRESET=ZERO)
LGO.
7/8/9 - END OF RECORD   Multipunch
7/8/9

     DATA DECK

6/7/8/9 - END OF INFORMATION   Multipunch
```

2. Compile And Execute ESD or FPE With CONMIN From Update Files

```
JOB card
USER card
CHARGE card
CALL, FTN176
ATTACH (OLDPL=ESDCON)
          or
ATTACH (OLDPL=FPECON)
UPDATE (F)
FTN (I,LCM=I,L=0,B=LGO)
RETURN (OLDPL, COMPILE)
ATTACH (OLDPL=CONMINS)
UPDATE (F)
FTN (I,LCM=I,L=0,B=LGO2)
RFL (EC=440)
LDSET (PRESET=ZERO)
LOAD (LGO,LGO2)
EXECUTE.
7/8/9
7/8/9
7/8/9

     DATA DECK

6/7/8/9
```

3. Execute ESD or FPE From Stored Binary Decks

Replace ATTACH of OLDPL, UPDATE, and FTN in Ex. 1 with

```
ATTACH(LGO=ESDCONB)
        or
ATTACH(LGO=FPECONB)
```

4. Execute ESD or FPE With CONMIN From Stored Binary Decks

Replace ATTACH'S, UPDATE'S, and FTN'S in Ex. 2 with

```
ATTACH(LGO=ESDCONB)
        or
ATTACH(LGO=FPECONB)
ATTACH(LGO2=CONMINB)
```

5. Restart ESD or FPE From Stored Solution

Insert

```
ATTACH(TAPE10=ESDRST)
        or
ATTACH(TAPE4=FPERST)
```

into the runstream prior to execution. In this example, ESDRST and FPERST are data files saved from previous runs.

6. Store A Restart Solution On File

Insert

```
DEFINE(TAPE11=ESDSAV)
        or
DEFINE(TAPE7=FPESAV)
```

into runstream prior to execution. DEFINE is equivalent to doing a REQUEST and CATALOG under the SCOPE operating system.

7. Store Data For Use In TWODBL Program

Insert

```
DEFINE(TAPE12=TWODAT)
```

into the runstream prior to execution.

b. Computer Resource Requirements

The amount of computer time required to run either the ESD or the FPE code with or without CONMIN will depend on a number of factors such as the number of iterations performed and the size of the computational grid. When linked with CONMIN, the ESD code requires about 200000_8 words of main memory to compile and execute plus approximately 413000_8 words of large core memory (LCM) for real time data storage. The FPE code plus CONMIN requires about 163000_8 words for execution and 431000_8 words of LCM for data storage.

SECTION III

VISCOUS ANALYSIS PROCEDURE

(1) Uses Three Programs -- TWODBL, LINKUP, LINKDN

1. GENERAL DESCRIPTION

The viscous analysis procedure involves using 3 programs: (TWODBL, LINKUP, LINKDN). TWODBL is a 2-D integral strip boundary layer program.[6] TWODBL is used to generate boundary layer displacement thickness (δ*) information at the wing control stations so that the δ*'s can be subtracted from a "fluid" wing geometry to produce a solid wing geometry or to add δ*'s to the solid wing geometry to produce a "fluid" wing. Inputs to TWODBL come from two sources: card input, and file input which has been previously cataloged. The card input provides parameters, constants, and flags which are needed to run the boundary layer program. The file input contains the surface pressures which were computed and saved by a previous potential flow solution.

The LINKUP program is used to add δ*'s to a solid wing geometry to obtain a "fluid" wing. The LINKDN program is used to subtract δ*'s from a "fluid" wing to obtain the solid wing geometry.

In order to start the design procedure using optimization with either the FPE or ESD codes, the user must first select a starting hard wing geometry. This wing must then be converted to an equivalent "fluid" wing. To do this, the hard wing must first be analyzed using either the ESD or FPE potential flow codes. This analysis run produces pressure distributions over the hard wing surface. These pressure distributions are then used in a TWODBL run to create a displacement thickness file. The user then runs LINKUP which accesses files containing hard wing ordinates and δ*'s and adds the δ*'s to the hard wing ordinates to produce a file containing the "fluid" wing ordinates. These

"fluid" ordinates are used to start the optimization design procedure.

The optimization design procedure using the inviscid potential flow codes, whether FPE or ESD, results in a wing geometry that produces the specified design pressure distributions. This geometry is the equivalent "fluid" wing geometry that the potential flow sees (hard wing + viscous boundary layer displacement thickness). In order to obtain a hard wing geometry that can now be used to build a model, or full scale wing, the boundary layer displacement thickness must first be computed and then subtracted from the "fluid" wing, at the wing control stations. To do this, the user runs TWODBL, and creates a displacement thickness file. The user then runs LINKDN, which accesses files containing "fluid" wing ordinates and δ^*'s, and subtracts the δ^*'s for the "fluid" wing ordinates to produce a file containing the hard wing ordinates.

Because these viscous runs are done only at the beginning and at the end of the design process and because it is important that displacement thicknesses are added or subtracted properly, it is suggested that the user carefully check the TWODBL run output.

NOTE: TWODBL is used to compute displacement thicknesses. These computations are done on a flat plate strip, the length of the strip being the chord length which must be input to TWODBL.

2. RELATION OF BOUNDARY LAYER STRIP LOCATIONS TO WING CONTROL STATION LOCATION

In general, the potential flow analysis codes compute surface pressures at spanwise locations that are not exactly at the same location as the control stations where airfoil ordinates are prescribed. The pressures are computed at stations determined by the grid distribution in the potential flow codes. What the user must do is specify (as input to the potential flow code) the

index of the computed pressure station, that is closest to each of the control stations. This is done through an integer array, KOUTBL. (See description of potential flow code input). If there are 5 control stations, 5 numbers should be input into KOUTBL. Because the spanwise grid distributions are fairly dense, the difference in locations of control stations and pressure stations will be small, and displacement thicknesses (corresponding to pressure stations) can be applied directly to the control stations.

The tip control station is, however, an exception. Since the potential codes do not in general compute accurate tip pressures, the following procedure should be followed. The last index input into KOUTBL should correspond to a pressure station in the region of 85% to 90% of the span. TWODBL will then compute the displacement thickness at the spanwise location determined by this index. The linking programs LINKDN and LINKUP will then use these displacement thicknesses to adjust the airfoil ordinates at the tip control station.

3. TWODBL OUTPUT NEEDED TO RUN LINKING PROGRAMS

There is a minimum of TWODBL output information that the user needs as card input to the linking programs. These inputs will be described later, in the section on the linking programs. We will concentrate here on inputs which require the user to make a judgment as to the appropriate values.

For both the LINKUP and LINKDN programs, one of the required inputs is the location of the separation point, if any. On the TWODBL output page whose heading is "PRINCIPAL BOUNDARY LAYER INFORMATION" will be found a number of columns. The first column is the point index. The column X/C is the streamwise point distribution at which the airfoil ordinates are given. The column headed by FORMI gives the boundary layer incompressible

form factor. The number of points printed depends on whether and where separation has occurred. For each upper and lower surface strip, the user will have to input the separation index. If there is no separation, then the index corresponding to X/C = 1 will be input. If there is separation, the last index printed will be input on the condition that the value for FORMI is less than 2.8. If FORMI is greater than 2.8, then the next smaller index is the one that will be input into the linking programs.

Here's an example. Assume there are 33 airfoil defining points with X/C = 1.0 at I = 33. For each strip where 33 points are printed, there was no separation. Then the index to use is 33. Assume that for two of the strips, separation occurs at the same streamwise location, and assume that the last index printed was I = 27. For one of the strips the value of FORMI at I = 27 was 2.78. Then for this strip the index is 27. For the other strip, the last index printed was also 27, but the value of FORMI at I = 27 was 2.82. Then the index to use for this strip is the next lower one, I = 26.

There is an exception to this rule. The exception involves cases where the displacement thickness is changing very rapidly at the point of separation. In this case it is necessary to take the index for separation (indicated by FORMI), one or two numbers smaller. This should be done because the separation streamlines in the linking program are determined by extrapolation. Taking the separation index at a point where the displacement thickness is changing very rapidly, would make such a streamline extrapolation unrealistic.

4. DESCRIPTION OF CARD INPUTS TO TWODBL

TWODBL reads a Tape 12 file which contains surface pressure and X locations and writes a Tape 10 file for use by LINKUP or LINKDN. Each strip requires a separate set of inputs. So if a wing has 5 control stations, there will be two strips at each control station and two sets of inputs for each control station corresponding to the upper and lower surface for a total of 10 input sets. The inputs start at the inward part of the wing and work out to the tip in the following sequence: Inboard upper surface, then inboard lower surface, then the next station upper surface, then the lower surface and so on. A detailed description of TWODBL may be found in Reference 6.

For each strip, the following must be input:

Card #1

Title Card

Card #2 8F10.0

GAM, R, PTZ, TTZ, UPMACH

Card #3 915, F10.5

NST, NVP, NTURB, KPVM, KEM, KSMTH, KSPLN, KLE, KATCH, CTHET

Card #4 8F10.0

DLAM, TLAM, DTURB, TTURB, RTRAN

Card #5 1615

KPRE, KGRAD, KSDE, KLAM, KMAIN, KPROF

Card #6 215, F10.0

ISAME, IADD, CHORD

Options Added

KPVM = 6 X, y, C_p, T_{wall} may be input in 4F10.0 format

T_{wall} need not be input, it is assumed to be T_{total}

KPVM = 7 This option must be used for operation with inputs generated by ESD or FPE codes.

Read ISAME, IADD, CHORD
(2I5, F10.0)

If ISAME = 1, X locations of C_p input, and X locations of airfoil defining points will be read from TAPE 12

If ISAME = 0, X locations will not be read

IADD = Number of X locations which correspond to the airfoil defining X/C locations

CHORD = Chord length at current input station.

For the first set of 6 input cards (inboard upper surface, set ISAME = 1 to read X locations. For subsequent sets, set ISAME = 0.

Dictionary of TWODBL Variables

GAM specific-heat ratio, γ

R gas constant, R, (ft)(lbf)/(slug)(^{o}R); J/(kg)(K)

PTZ inlet or upstream relative total pressure (station 0), P_0', lbf/ft^2; N/m^2

TTZ inlet or upstream relative total temperature (station 0), T_0', ^{o}R; K

UPMACH inlet or upstream Mach number relative to surface, M_0

NST integer number of input stations ($\leq$100) along boundary-layer surface

NVP integer number of points desired in velocity profile at each station

NTURB integer number of station, if any, at which user wishes turbulent boundary layer to begin (NTURB is usually zero, allowing program to calculate position of transition to turbulent boundary layer. NTURB may also be given any value from 1 to NST. If NTURB = 1, initial values must be given for DTURB and TTURB. If NTURB > 1, initial values may or may not be given.)

KPVM	integer from 1 to 7 indicating which form of surface flow distribution is given as inputs. Note: KPVM must be set to 7 when TWODBL is used in the viscous linking procedure.

Pressure. 1

Free-stream velocity 2

Free-stream Mach number 3

Ratio of pressure to total pressure 4

Ratio of free-stream velocity to free-stream critical velocity 5

(See Added Options, KPVM = 6;7)

KEM	integer (0 to 1) indicating which of the two allowable sets of units are used in input:

English (pounds force, slugs, feet, seconds, degrees Rankine, and foot-pounds) 0

Metric (Newtons, kilograms, meters, seconds, degrees Kelvin, and Joules) 1

KSMTH	integer (0, 1, 2, . . .) indicating number of times distribution of free-stream velocity is to be smoothed prior to computation of surface gradients
KSPLN	integer (0 or 1) indicating manner in which surface gradients are to be calculated:

Weighted-difference technique. 0

Spline curve-fit technique 1

KLE	integer (0 to 1) indicating type of initial condition existing at station 1:

Stagnation point or initial values given. 0

Sharp leading edge. 1

KATCH integer (0 or 1) indicating whether laminar-boundary-layer separation (if encountered) should reattach as a turbulent boundary layer:

Separation and stop. 0

Reattach 1

CTHET real variable used when KATCH = 1, indicating ratio of momentum thickness after reattachment to momentum thickness at laminar separation

DLAM initial displacement thickness, if any, of laminar boundary layer at station 1, ft; m (DLAM may be zero or have some finité value.)

TLAM initial momentum thickness, if any, of laminar boundary layer at station 1, ft; m (TLAM may be zero or have some finite value.)

DTURB initial displacement thickness, if any, of turbulent boundary layer, ft; m (DTURB may be given for station designated by NTURB, or for station at which transition is calculated by program.)

TTURB initial momentum thickness, if any, of turbulent boundary layer, ft; m (see DTURB)

RTRAN Momentum thickness Reynolds number used to initiate computation of the turbulent transition index, NTURB (i.e. NTURB is computed only when $R_e \geq$RTRAN).

KPRE integer (0 or 1) indicating whether printing of output from PRECAL is desired (see OUTPUT):

Output suppressed. 0

Output printed. 1

KGRAD integer (0 or 1, see KPRE) indicating whether printing of surface velocity and Mach number is desired.

KSDE integer (0 or 1, see KPRE) indicating whether printing of solutions of laminar and turbulent differential equations is desired.

KLAM integer (0 or 1, see KPRE) indicating whether printing of laminar calculations for location of instability and transition is desired.

KMAIN integer (0 or 1, see KPRE) indicating whether printing of principal calculated boundary-layer parameters is desired.

KPROF integer (0 or 1, see KPRE) indicating whether printing of velocity profiles is desired.

X array of X-coordinates of input stations, ft; m

Y array of Y-coordinates of input stations, ft; m

PRES array of static pressure P at X-Y input stations, lbf/ft^2; N/m^2

UE array of free-stream velocities u_e relative to surface at X-Y input stations, ft/sec; m/sec.

ME array of free-stream Mach numbers M_e relative to surface at X-Y input stations

POPTZ array of ratios of static pressure to inlet relative total pressure P/P'_0 at X-Y input stations

VOVCR array of ratios of relative free-stream velocities to inlet relative critical velocity $u_e/u_{cr,0}$ at X-Y input stations ($u_{cr,0}$ is the speed of sound at Mach 1, and is only a function of inlet relative total temperature.)

$$u_{cr,0} \sqrt{\frac{2\gamma R}{\gamma+1} T'_0}$$

TWAL array of static wall temperatures at X-Y input stations, $^{\circ}R$; K (if TWAL is unknown and surface is nearly isothermal, the value of TTZ may be used for TWAL.)

5. HOW TO USE THE LINKUP PROGRAM

In order to obtain an effective "fluid" wing from a hard geometry, run the LINKUP program. The LINKUP program requires both card input, and input on a TAPE7 file. The TAPE7 file is from a previous TWODBL run and contains wing section geometries and displacement thickness information. The following card inputs are required:

6. CARD INPUT DESCRIPTION FOR LINKUP

CARD #1

NC, NS (215)

NC = number of X/C points at which control station airfoil ordinates were specified (in the potential flow code).

NS = number of surface strips which TWODBL calculated. For example, for a 5 control station wing, with two strips per control station, NS = 10.

CARD #2

NTR (1615)

NTR = Array of indices of locations where transition was specified in TWODBL. There will be NS values input for NTR.

The sequence of indices is inboard control station upper surface first, then inboard control station lower surface and so on, for each control station proceeding out across the span.

CARD #3

NT (1615)

NT - Array of indices where separation occurs. See TWODBL description on how to determine these indices. The sequence of indices is the same as for NTR.

7. HOW LINKUP TREATS SEPARATION

A very simple model is used in LINKUP to obtain "fluid" ordinates in regions of separation. On the upper surface the slope of the fluid airfoil is taken to be a constant in the region aft of separation. On the lower surface in the cove region, the slope of the fluid airfoil is taken to be a constant aft of separation, until the point at which the difference between the fluid and hard ordinates is equal to the displacement thickness at separation. After this point, the displacement thickness is taken to be a constant and equal to the displacement thickness at the separation point.

8. LINKUP OUTPUT

LINKUP produces no output on unit 6. All output is written on TAPE8. This output consists of control station airfoil geometries for the fluid wing. The fluid wing section geometries on TAPE8 are in a format suitable for input into either of the two potential flow analysis codes. TAPE8 should thus be cataloged so that the user doesn't have to punch the control station fluid airfoils. To see LINKUP output, copy TAPE8 to print before cataloging.

9. HOW TO USE THE LINKDN PROGRAM

In order to obtain a hard wing geometry from the fluid wing that comes out of the optimization process we run the LINKDN program. The LINKDN program requires both card input and input on a TAPE7 file. The TAPE7 file is from a previous TWODBL run, and contains wing section geometries and displacement thickness information. The following card inputs are required to run LINKDN.

10. CARD INPUT DESCRIPTION FOR LINKDN

CARD #1

TOCTE (F10.6)

TOCTE is a constraint on the trailing edge thickness as a fraction of local chord. During the process of obtaining a hard wing from the

fluid wing, the trailing edge thickness cannot go below TOCTE.

CARD #2

NC, NS, LSMTH (3I5)

NC is the number of chordwise X/C points in the control station airfoil definition.

NS is the number of surface strips which is equal to twice the number of control stations.

LSMTH is the number of smoothings to be done on the final hard wing sections.

CARD #3

NT (16I5)

NT = Array of indices of locations where transition was specified in TWODBL. There will be NS values input for NT. The sequence for specifying NT is inboard control station first - upper surface index, then lower surface index; proceeding in this fashion inboard to outboard.

11. *LINKDN OUTPUT*

LINKDN produces no output on the standard print file, UNIT #6. All output is written on a TAPE8 file, which should be saved for subsequent input to the potential flow codes. LINKDN produces output identical in form to that of LINKUP, which consists of wing control station geometries. To see the output of LINKDN, the user should copy TAPE8 to a print file before saving it.

12. JOB CONTROL REQUIREMENTS

TWODBL and the linking programs have run on both the CDC 7600 and the CYBER 176 computers. The following sample decks illustrate the job control cards required to execute TWODBL and the linking programs on either computer.

Sample Decks:

1. Execute TWODBL from UPDATE program library and store output.

CYBER 176

```
Job Card
USER Card
CHARGE Card
CALL, FTN176.
ATTACH (TAPE12 = TWODINP)
ATTACH (OLDPL = TWODBL)
UPDATE, F.
FTN, I, L=0, LCM=I.
DEFINE (TAPE10 = TWODOUT)
RFL, EC=100.
LDSET, PRESET = ZERO.
LGO.
REWIND, TAPE10.
COPYSBF, TAPE10, OUTPUT.
REWIND, TAPE10.
7/8/9  Multipunch
7/8/9  Multipunch
     INPUT DECK
6/7/8/9 Multipunch
```

CDC 7600

```
Job Card
ACCOUNT Card
ATTACH (TAPE12, TWODINP)
ATTACH (OLDPL, TWODBL)
REQUEST (TAPE10, *PF)
UPDATE, F.
FTN, I, L=0, LCM=I.
LDSET, PRESET = ZERO.
LGO.
REWIND, TAPE10.
COPYSBF, TAPE10, OUTPUT.
REWIND, TAPE10.
CATALOG (TAPE10, TWODOUT, ID= )
7/8/9
7/8/9
       INPUT DECK
6/7/8/9
```

2. Execute LINKUP or LINKDN from UPDATE Program Library

CYBER 176

```
Job Card
USER Card
CHARGE Card
CALL, FTN176.
ATTACH (TAPE7 = TWODOUT)
DEFINE (TAPE8 = LINKOUT)
ATTACH (OLDPL = LINKS)
UPDATE, Q.
FTN, L=0.
LDSET, PRESET = ZERO.
LGO.
REWIND, TAPE8.
COPYSBF, TAPE8, OUTPUT.
7/8/9     Multipunch
*COMPILE LINKUP
      or
*COMPILE LINKDN
7/8/9
      INPUT DECK
6/7/8/9   Multipunch
```

CDC 7600

```
Job Card
ACCOUNT Card
ATTACH (TAPE7, TWODOUT)
REQUEST (TAPE8, *PF)
ATTACH (OLDPL, LINKS)
UPDATE, Q.
FTN, L=0.
LDSET, PRESET = ZERO.
LGO.
REWIND, TAPE8.
COPYSBF, TAPE8, OUTPUT.
REWIND, TAPE8.
CATALOG (TAPE8, LINKOUT, ID =    )
7/8/9
*COMPILE LINKUP
      or
*COMPILE LINKDN
7/8/9
      INPUT DECK
6/7/8/9
```

SECTION IV

WING-PYLON-NACELLE COMPUTER CODE

1. GENERAL DESCRIPTION OF PROGRAM

The transonic wing-pylon/nacelle interference program (TALA) consists of three major parts. The first part is the ESD wing code which is essentially the same as the ESD wing code used in the optimization design procedure. The major differences in the ESD wing code used in TALA are the modifications made to incorporate the pylon and a different input sequence for the wing control station ordinates. The second part of TALA are the routines for solving the nacelle flow field. The third part consists of a driver program and boundary condition transfer routines, used to cycle back and forth between the wing-pylon and nacelle solutions. Fig. 3 shows the overall logic.

TALA may be operated in a number of ways: 1) A wing alone solution may be obtained, 2) A nacelle alone solution may be obtained, 3) The nacelle alone solution may be imposed as boundary conditions on a wing solution. In this mode, the nacelle boundary conditions that are imposed are not changed, and the effect of the wing on the nacelle is not accounted for. This will be referred to as the non interacting mode, 4) A mutual interference solution where the nacelle and wing are updated with each call to the corresponding program. In this mode, both the effects of the nacelle on the wing, and the effects of the wing on the nacelle are obtained. This will be referred to as the interacting mode.

The nacelle subroutines are set up to solve a flow through nacelle geometry with no center hubs or spinners. In the nacelle alone mode, boundary conditions are specified at upstream infinity, downstream infinity, and radial infinity. The nacelle solution is obtained on a computational grid which maps the infinity boundary conditions to a finite computational domain. More detailed information on grids and solution procedure can be found in Ref. 7.

2. GENERAL DESCRIPTION OF CARD INPUT SEQUENCE

Here we present a short narrative description of some of the more important input parameters.

Namelist Master is Input First

This namelist controls the mode in which the program is run, and also controls the iteration counts. If no mode flags are specified, the default mode will be the interacting mode.

NCYCLE specifies the total number of cycles that will be made between the nacelle and wing-pylon portions of the program. From our experience NCYCLE should be set to 10 or larger. ITERNAC specifies the number of nacelle solution iterations for each cycle. Recommend ITERNAC = 30. ITERATW specifies the number of wing-pylon solution iterations for each cycle. Recommend ITERATW = 30.

Namelist Flag is Input Next

These inputs are used to set up the nacelle computation. See detailed input description for more information.

Namelist Stretch is Input Next

These inputs are used to set up the nacelle grid. See detailed input description.

Nacelle geometry is input next consisting of coordinates which either have or have not been scaled by the nacelle chord. There are 8 sections. (See Fig. 4). The coordinates are input 8 to a card in 8F10.0 format. The inner surface X or X/C values are read in first. Next, the inner surface section ordinates are read in. The first set of ordinates correspond to K=1 or THETA=22.5°. Following the first set of ordinates, the flag SAMEIN is read. If SAMEIN = .T. then the second set of ordinates is the same as the first set, and these ordinates do not have to be read. SAMEIN is read for each section from K=1 to

NTHET. NTHET is set equal to 8 inside the program. At any K for which the section ordinates are not identical to the preceding section, SAMEIN should be set to FALSE and the ordinates read in 8F10.0 format.

After the inner surface nacelle geometry comes the input for the outer surface nacelle geometry in a similar sequence. The outer surface can be defined at X or X/C values that are different from those used to define the inner surface.

The Next Set of Inputs is for the Wing

The wing inputs are essentially the same as those described in Subsections 3-b and c of this volume with the following exceptions. In the current program, only the fine grid system is used and the input card sequence for the airfoil section ordinates is different. The airfoil sections are input after the planform definition inputs and require the following cards:

1. ATITLE (1 Card, 8A10)

   80 Character Airfoil Section Description

2. NPAN, INU, INL, KSMTHS (1 Card, 8I10)

   NPAN = No. of span stations at which airfoil ordinates are input - at least two stations required .LE. 11

   INU = No. of upper surface airfoil ordinates .LE. 90

   INL = No. of lower surface airfoil ordinates.LE. 90

   KSMTHS = No. of times computed surface slopes are smoothed.

3. YP(N), THETP(N), N=1,NPAN (NPAN/4 Cards, 8F10.0)

   YP = Fraction of semispan at which airfoils are defined.

   THETP = Twist angle, degrees, at YP - Positive IS L.E. Up

4. XINU(I), I=1, INU (INU/8 Cards, 8F10.0)

   X/C at which airfoil upper surface ordinates are input.

5. XINL(I), I=1, INL (INL/8 Cards, 8F10.0)

X/C at which airfoil lower surface ordinates are input.

6. ISAME (1 Card, 14L5)

ISAME = F to input airfoil ordinates

= T use previously defined airfoil

7. ZUP(I,N), I=1, INU (INU/8 Cards, 8F10.0)

Upper surface airfoil ordinates/chord - Required if ISAME = F

8. ZLP(I,N),I=1,INL (INL/8 Cards, 8F10.0)

Lower surface airfoil ordinates/chord - Required if ISAME = F

NOTES

A. ISAME must = F for first YP

B. Repeat Cards 6 through 8 NPAN times

The control parameter, AFIN, is input via namelist FLAG. Also, the last card in the planform definition block has been moved inside the airfoil section input block shown above. After the wing planform and section ordinate inputs is an input flag PYLN. If PYLN = T then a pylon geometry must be input. If PYLN = F, then no pylon computation is done, and no pylon input geometry is required.

The next card inputs ETAP, and ALPHP in 2F10.0 Format. ETAP is the dimensional spanwise distance at which the pylon is located. ALPHP is the pylon toe-in angle. ETAP and ALPHP must always be input even if a wing alone solution is being done because ETAP is needed to set up the grids. If NACGEN in namelist FLAG was set to true, it means that a nacelle-pylon-wing computational grid will be automatically generated.

Following the cards containing the pylon geometry is a card which inputs HNAC and XFNAC in 2F10.0 format. HNAC and XFNAC give the location of the front face of the nacelle, and must always be input to set up the grid. See Figure 5.

3. DETAILED INPUT DESCRIPTION FOR WING-PYLON-NACELLE CODE

a. Control Flags and Initial Conditions

NOTE: Default values in parentheses.

NAMELIST/MASTER/

NCYCLE	= # of interaction cycles between nacelle and wing	(10)
ITERNAC	= # of nacelle code internal solution iterations for each cycle through nacelle code	(30)
ITERATW	= # of wing code internal solution iterations for each cycle through wing code.	(30)
WALONE	= Flag which determines whether a wing only solution is wanted	(F)
SAVESOL	= Flag which determines whether nacelle solution field will be written on tape file #9 for future restart.	(T)
NALONE	= Flag which determines whether a nacelle alone solution is wanted.	(F)
NOINTER	= Flag which determines if a non-interacting nacelle solution is wanted (isolated nacelle solution imposed on wing as boundary conditions with no cycling between nacelle and wing).	(F)

NOTE: If WALONE = .F., NALONE = .F., and NOINTER = .F., then the program will run in the interaction mode.

NAMELIST/FLAG/

ALPHA	= Nacelle Angle of Attack (Degrees)	(0.0)
BETA	= Nacelle Yaw Angle. Toe-in is negative (Degrees)	(0.0)
NF	= # of streamwise grid pts. in front of nacelle	(7)
NA	= # of streamwise grid pts. on nacelle	(25)
NB	= # of streamwise grid pts. behind nacelle	(6)
NE	= # of radial grid pts. outside of nacelle	(12)

NI	= # of radial grid pts. inside nacelle	(14)
ALP	= Fraction of grid pt. interval that trailing edge is off grid line.	(0.5)
NALP	= If NALP = 0 then ALP is automatically set to zero If NALP = 1 then ALP must be input	(1)
RESTART	= If .T. then nacelle solution is being continued from a previous solution (Read in on Tape File #8)	(F)
MIN	= Free stream Mach number (floating point number)	
WSB	= Subsonic relaxation factor	(1.6)
WSP	= Supersonic relaxation factor	(0.92)
ITERM	= Nacelle surface pressure information will be printed every ITERM iterations.	
NESD	= 0 Solve standard small disturbance equation = 1 Solve extended small disturbance equation	(0)
NXBODL	= # of nacelle input body pts. on inner surface.	
NXBODU	= # of nacelle input body pts. on outer surface.	
CHORD	= Nacelle chord length.	
NSWCH	= F, program will not switch to extended small disturbance equation. = T, program will switch to extended small disturbance equation after ITERESD iterations.	(F)
KSMT	= # of smoothings to be done on nacelle input ordinates.	(4)
SMBOD	= .T. Smooth nacelle ordinates = .F. No smoothing	(T)
SMSLOP	= .T. Smooth nacelle surface slopes = .F. Do not smooth	(T)
KSMTS	= # of smoothings to be done on nacelle surface slopes.	(4)

ITERESD = # of iterations after which extended small disturbance terms are turned on (if NSWCH = .T.) (30)

SCALE = .T. nacelle geometry is input already Scaled by the nacelle chord.

= .F. input nacelle geometry is in physical units (consistent with units for nacelle chord) (F)

NOTE: Nacelle geometry description must be in units consistent with the wing geometry description.

NAMELIST/STRETCH/

A1	= Axial grid stretching factor	(0.05)
A2	= Axial grid stretching factor	(4.0)
A3	= Axial grid stretching factor	(0.05)
A4	= Axial grid stretching factor	(2.5)
CR	= Radial grid stretching factor	(0.35)
A3R	= Radial grid stretching factor	(0.10)
A4R	= Radial grid stretching factor	(2.0)
RS	= Nacelle hi-lite radius	

(This is the distance from the nacelle centerline to leading edge of the nacelle. This number must be the same as the first number input for nacelle ordinates at X/C = 0.)

b. Inputs for Nacelle Geometry Description

XBODL (8F10.0) Array of inner surface X or X/C nacelle defining points, 8 to a card.

RBODI (8F10.0) Array of inner surface section ordinates at K=1, THETA = 22.5°. These ordinates are defined with the origin at the nacelle centerline.

The next two cards control ordinate input for K=2 to 8 (THETA from 67.5^{o} to 337.5^{o}).

SAMEIN (LOGICAL) = .T. The next set of ordinates is the same as the previous set.

= .F. The next set of ordinates is different from the previous set, and will be input.

RBODI (8F10.0) Array of inner surface section ordinates (8 to a card) at K>1. These must be input for any section where SAMEIN = .F.

EXAMPLES: If all eight nacelle defining sections are the same (nacelle is symmetrical) then the input will consist of the initial section at K=1, followed by seven cards inputting SAMEIN = .T. If all eight nacelle defining sections are different, then the input will consist of the initial section of K=1 followed by seven sets of SAMEIN = .F., and RBODI.

XBODU (8F10.0) Array of outer surface X or X/C nacelle defining points, 8 to a card.

RBODE (8F10.0) Array of outer surface section ordinates at K=1, THETA = 22.5^{o}.

SAMEIN (LOGICAL) = .T. The next set of ordinates is the same as the previous set.

= .F. The next set of ordinates is different from the previous set, and will be input.

RBODE (8F10.0) Array of outer surface ordinates at K>1.

NOTE: Input sequence for outer section ordinates is the same as for the inner ordinates.

c. Inputs for Wing and Pylon

The inputs required to compute the wing are basically the same as those described previously for the ESD code. Only the changes to the inputs to accommodate the pylon/nacelle will be described here.

The parameter NACGEN has been added to NAMELIST GPARM.

NACGEN = .T. The wing grid will be automatically generated to accommodate the pylon/nacelle.

= .F. Standard ESD code grid procedures will be used.

NOTE: It is recommended that the code be run with NACGEN = .T.

The following inputs have been added immediately following the cards containing the wing section definitions:

PYLN (LOGICAL) = .T. Pylon will be computed.

= .F. Pylon will not be computed, and pylon data cards will be omitted.

See Figure 5 for a schematic of pylon geometry setup.

ETAP, ALPHP (2F10.0)

ETAP = Spanwise pylon location

ALPHP = Pylon toe-in angle (Degrees; toe-in is positive, note difference in sign from nacelle toe-in angle)

NSEGL (I10)

NSEGL = # of pylon leading edge segments

XPL, ZPL (4F10.0)

XPL = X Coordinate of segment end point (Streamwise)

ZPL = Z Coordinate of segment end point (Vertical)

There will be two pairs of (XPL, ZPL) on each card and one card for each segment. Segment end points will be input starting at the nacelle and going up towards the wing. Note: The pylon can have at most two leading edge segments and two trailing edge segments.

NSEGT (I10)

NSEGT = # of pylon trailing edge segments

XPT, ZPT (4F10.0)

XPT = X Coordinate of segment end point

ZPT = Z Coordinate of segment end point

There will be two pairs of (XPT,ZPT) on each card, and one card for each segment. Segment end points will be input starting at the nacelle and going up toward the wing.

Note: The zero reference point for XPL, XPT, ZPL, ZPT is the wing leading edge at a spanwise position corresponding to the pylon location. Thus, values of ZPL and ZPT will be negative. XPL, XPT will be negative if they correspond to a point in front of the leading edge.

NOPP (I10)

NOPP = # of points defining the pylon section.

XPY (8F10.0)

XPY = Array of X/C values defining the pylon section. X=0 at pylon leading edge, and C = pylon chord. There are NOPP numbers, 8 to a card.

YCOUT (8F10.0)

YCOUT = Array of outboard pylon section ordinates corresponding to XPY. There are NOPP numbers, 8 to a card.

YCINB (8F10.0)

YCINB = Array of inboard pylon section ordinates corresponding to XPY. There are NOPP numbers, 8 to a card.

HNAC, XFNAC (2F10.0)

XFNAC = Distance from leading edge of wing to face of nacelle. The leading edge location is the one corresponding to the spanwise

location of the pylon. If face of nacelle is in front of leading edge, then XFNAC will be input as a negative number.

HNAC = Vertical distance from wing reference plane to centerline of nacelle. HNAC will be input as a negative number.

NOTE: Regardless of whether PYLN is true or false, the two cards containing ETAP, ALPHP and HNAC, XFNAC must always be input.

The remainder of inputs is the same as previously described except that the exterior mesh option cannot be used, and if NACGEN = .T. is selected, then the grid parameters input through NAMELIST GPARM will be overridden.

4. JOB CONTROL REQUIREMENTS

a. Job Control Cards

The wing-pylon-nacelle code has been run on two Control Data computers - the CYBER 176 under the NOS operating system and the 7600 under the SCOPE operating system. Because of program size restrictions on the 7600, the wing-pylon/nacelle code must be segmented to run on this computer. The addition of segmentation directives to the 7600 runstream is the major difference in the job control requirements of the two computers. The following sample input decks illustrate the job control cards required to run the program on either computer.

Sample decks:

1. Compile and execute from UPDATE program library.

   CDC 7600

```
Job Card
ACCOUNT Card
ATTACH (OLDPL, TALAF)
UPDATE, F.
FTN,I,L=0,LCM=I, PL=30000.
LDSET (PRESET = ZERO)
SEGLOAD (B=A)
LOAD (LGO)
NOGO.
```

```
A.
EXIT.
7/8/9 - Multipunch   End of Record
7/8/9
        SEGMENTATION DIRECTIVES
7/8/9
        INPUT DECK
6/7/8/9     END OF FILE
```

CYBER 176

```
Job Card
USER Card
CHARGE Card
CALL, FTN176.
ATTACH (OLDPL = TALAF)
UPDATE, F.
FTN(I,L=0, LCM=I, PL=30000)
RFL, EC=550.
LDSET (PRESET = ZERO)
LGO.
7/8/9
7/8/9
        INPUT DECK
6/7/8/9
```

2. Execute from previously stored binary file.

Replace ATTACH's, UPDATE's and FTN's in Ex. 1 with

```
ATTACH(LGO,TTBIN) - 7600
          or
ATTACH(LGO=TTBIN) - CYBER 176
```

3. Restart from stored nacelle and wing solutions and store new solution

CDC 7600

Insert

```
REQUEST (TAPE11, *PF)
REQUEST (TAPE9, *PF)
ATTACH (TAPE8, file, ID=   ); (Nacelle Solution)
ATTACH (TAPE10, file, ID=   ); (Wing Solution)
```

before execution.

Insert

```
CATALOG (TAPE9, filename, ID=   ); (Nacelle Solution)
CATALOG (TAPE11,filename, ID=   ); (Wing Solution)
```

after execution.

CYBER 176

Insert

```
DEFINE (TAPE9 = filename)
DEFINE (TAPE11 = filename)
ATTACH (TAPE8 = filename)
ATTACH (TAPE10 = filename)
```

before execution.

Segmentation Directives

The following segmentation directives are required to run on the CDC 7600 computer.

```
TREE TALA-(NACELLE-(GRID),MAIN-(INPUT)
GRID INCLUDE METRIC,SLOPPY,SMTH,SPLN2
NACELLE INCLUDE TRID,AXIS,SETIN
NACELLE INCLUDE SHAZ,CUTOUT
NACELLE INCLUDE OUTNAC
MAIN INCLUDE INTERP,SOLVE,PYLON,STORE,FARBDY,PFINT,WNGBDY,PCINT,
  GCALC,DBNDY,OUTP,FORCP,FORCE,SIMP,INPUT
INPUT INCLUDE SETUP,SETUPX,MESH,TCOEF,TCOEFX,MESHIN,WINGCO,PYLCO,SLOPY,
SPLN1,SMTH,IC,GRIDGEN
NACELLE GLOBAL PHI-SAVE
TALA GLOBAL $Q8.10.$,$FCL.C.$
     GLOBAL     INTER,INDIX,METRICS,CALSUB,SAVEN
     GLOBAL RPM,RP,RCM,THCM,XPM,TPM,XCM,INDEX
     GLOBAL FLAGS,RELAXP,PARM,WING,GRIDN,LCO
     GLOBAL LARGN,XYCOE,TEMP,PYIN,ETERMS,JUMP,WINGBC
     GLOBAL $STP.END$,$10.BUF.$
MAIN GLOBAL LARGX,EXTER,INDEXX,LCOX,MESHCO,OLD
        END
```

b. Computer Resource Requirements

The wing-pylon/nacelle code requires approximately 263000_8 words of core to load and execute the program and about 505000_8 words of large core memory (LCM) for run time data storage on the CYBER 176. Because of the size of the program, the segmentation described in the preceding section must be performe to execute the program on the CDC 7600 computer. The longest segment will require about 61000_8 words of small core memory (SCM) and about 452000_8 words of LCM.

REFERENCES

1. Ballhaus, W. F., Bailey, F. R., and Frick, J., "Improved Computational Treatment of Transonic Flow About Swept Wings", NASA CP-2001, Nov. 1976.

2. Hinson, B. L., "Calculation of Inviscid Transonic Flow About Isolated Wings", Lockheed-Georgia Company Report LG77ER0242, Dec. 1977.

3. Jameson, Antony and Caughey, D. A., "Numerical Calculation of Transonic Flow Past A Swept Wing", ERDA Research and Development Report COO-3077-140, June 1977.

4. Vanderplaats, G. N., "CONMIN - A Fortran Program for Constrained Function Minimization - User's Manual", NASA TMX-62282, August 1973.

5. Brandt, L. G. and Lores, M. E., "User's Guide for Program CONMIN", Lockheed-Georgia Company IDC E-74-02-77.

6. McNally, W. D., "FORTRAN Program for Calculating Compressible Laminar and Turbulent Boundary Layers in Arbitrary Pressure Gradients", NASA TND-5681, 1970.

7. Srokowski, A. J., Shrewsbury, G. D., and Lores, M. E., "A Transonic Mutual Interference Program for Computing the Flow About Wing-Pylon/Nacelle Combinations, AIAA Paper No. 80-1333, July 1980.

8. Klunker, E. B., "Contribution to Methods for Calculating the Flow About Thin Lifting Wings at Transonic Speeds - Analytical Expressions for the Far Field", NASA TND-6539, 1971.

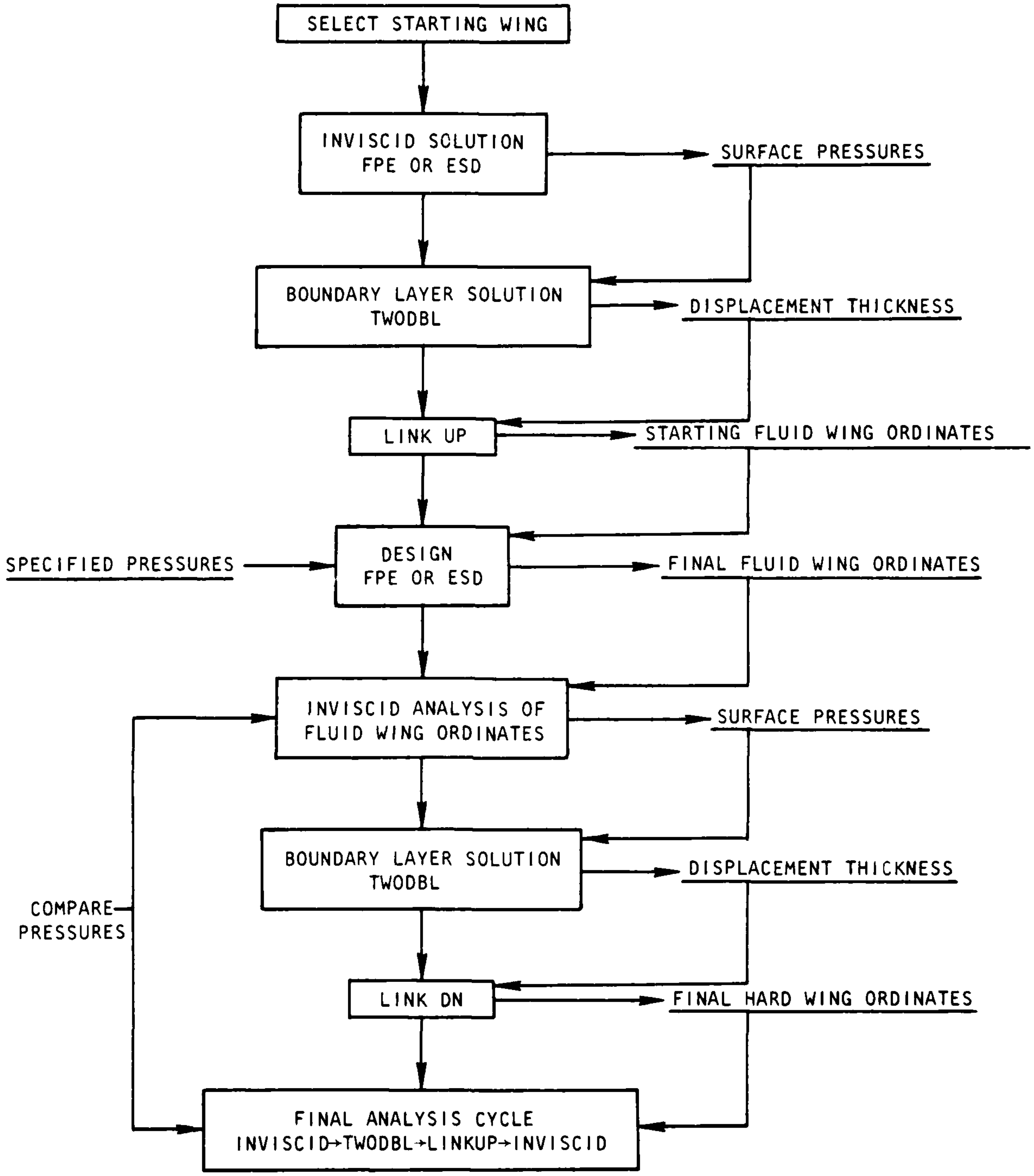


Figure 1. Flow Chart of Design Procedure

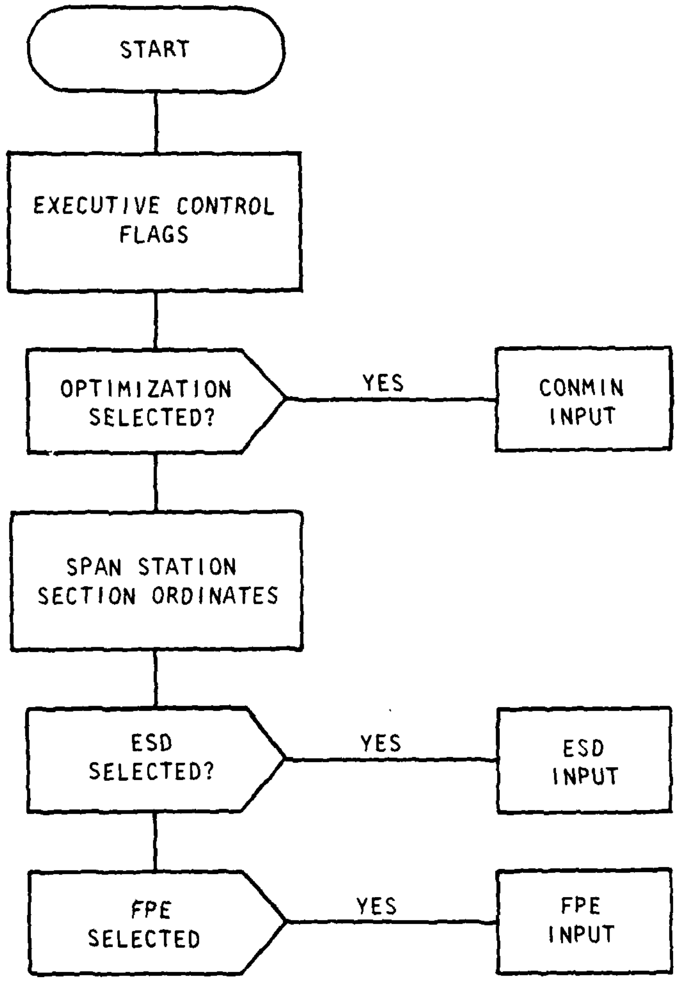


Figure 2. Input Sequence for ESD and FPE Codes

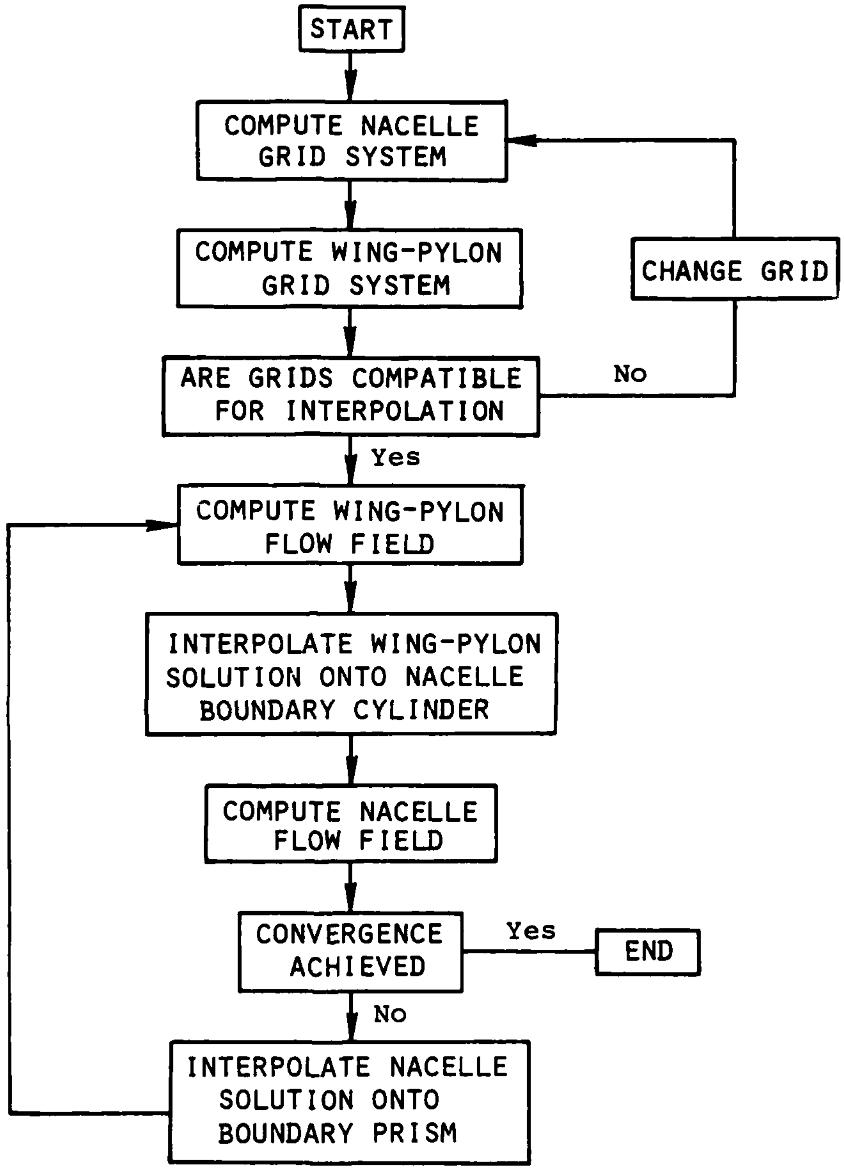


Figure 3. Wing-Pylon-Nacelle Solution Procedure

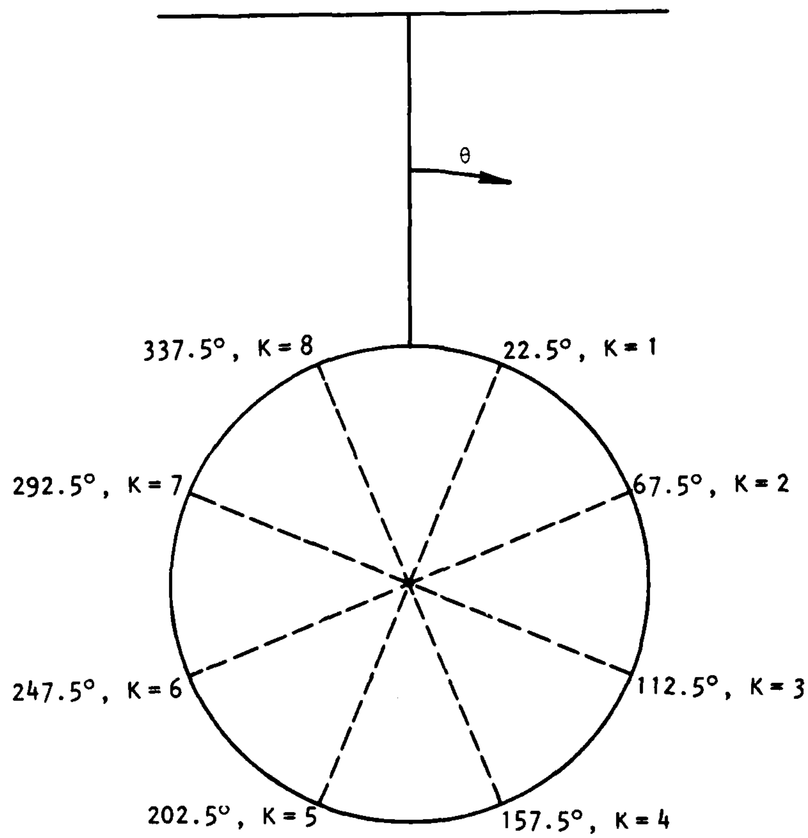


Figure 4. Nacelle Radial Solution Line Distribution

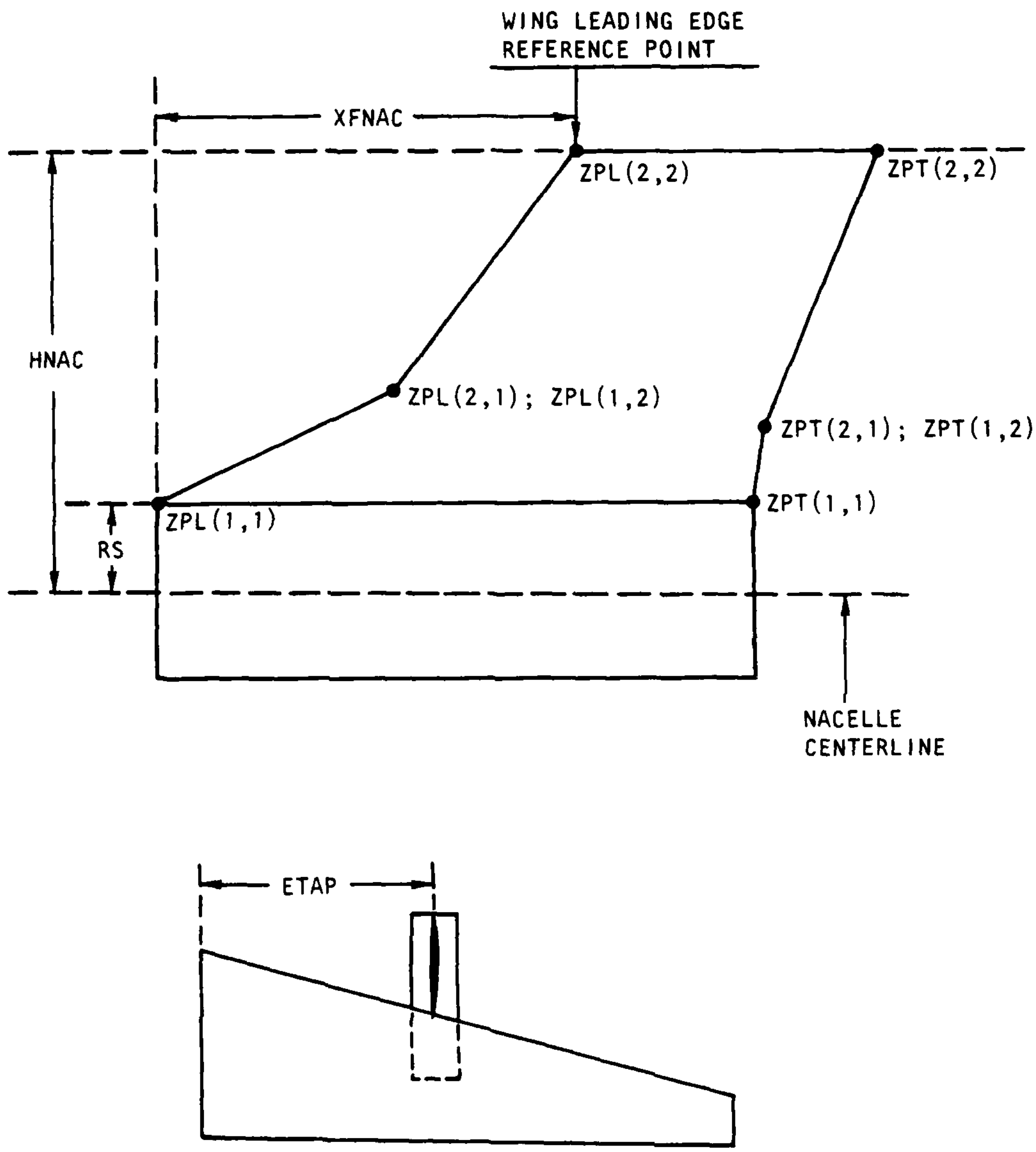


Figure 5. Wing-Pylon-Nacelle Geometry Input Relationships

APPENDIX A

SAMPLE INPUT DECKS

A.1 SAMPLE INPUT FOR ESD + CONMIN CODE

```
$CFLGIN
     FESD=.T.,KOUT=1,5,9,15,21,24,23*30,F2DBLS=.T.,K2DBL=5,
     KOUTBL=1,5,9,15,21,OPTM=.T., $
     CONMIN NAMELIST
$OPTIN
NPRINT=5,NV=8,ITMAX=2,NCON=0,NSIDE=0,ICNDIR=0,NSCAL=0,NFDG=0,
FDCH=.002,FDCHM=.0002,CT=.05,CTL=.001,CTMIN=.01,CTLMIN=.001,
THETA=1.,PHI=5.,DELFUN=.0001,DABFUN=1.E-06,LINOBJ=0,ITRM=5,VLB=20*-500.,
VUB=20*500.,ISC=200*0,SSCAL=20*0.,ALPCON=.02,B1CON=4.0,CLDSN=.6,
ALPHAX=.1,
ABOBJ1=.1,
CMDSN=-.1175,OBJCON=.1,ICONCP=1,ICONCL=1,ICONCM=1,ICNTHK=1, $
      KSD      KSURF       KCP        ILE        ITE      NCP1       NCP2       NVT
       4         1          16         64         79        64         69         15
      DESIGN VARIABLES
1.         1.         1.         1.         1.         1.         1.         1.
1.         1.         1.         1.         1.         1.         1.
      DESIGN VARIABLES USED
       1         2          4          5          6          7          8         14
      DESIGN CP VALUES
      -.95      -.95       -.94       -.94       -.94       -.93       -.93       -.92
      -.92      -.91       -.90       -.89       -.88       -.87       -.86       -.85
    ZTEMAX   ZTEMIN
.014       .022
      SECTION ORDINATES
T
          5          33          33          0
0.00000   .002410    .009610    .021530    .038060    .05904     .084270    .113490
.146450   .182800    .22221     .26430     .308660    .354860    .402450    .45099
.5000     .549010    .59755     .645140    .69134     .7357000   .77779     .81720
.85355    .886510    .91573     .940960    .961940    .978470    .990390    .997590
1.000
0.0000    .002408    .009607    .021530    .038060    .059039    .084265    .113495
.146447   .182803    .222215    .264302    .308658    .354858    .402455    .450991
.5000     .549009    .597545    .645142    .691342    .735698    .777785    .817197
.853553   .886505    .915735    .940961    .961940    .978470    .990393    .997592
1.000
F
.0179     .0322                 .04282     .05139     .05839     .06441     .06971     .07390
     .07702     .07950     .08109     .08120     .07996     .07751     .07440     .07066
     .06637     .06153     .05643     .05105     .04544     .03976     .03422     .02891
     .02388     .01913     .01466     .01068     .00728     .00451     .00242     .00111
     .00066
.0179     -.0001     -.0172     -.0316     -.0434     -.05188    -.05833    -.06355
    -.06717    -.06942    -.07011    -.06953    -.06743    -.06403    -.05948    -.05380
    -.04739    -.04056    -.03341    -.02642    -.02003    -.01468    -.01057    -.00730
    -.00474    -.00296    -.00191    -.00155    -.00141    -.00104    -.00089    -.00082
    -.00067
F
.0131     .0306      .0434      .0512      .0579                 .06377     .06931     .07359
     .07695     .07937     .08059     .08049     .07918     .07698     .07401     .07041
     .06625     .06160     .05657     .05122     .04566     .04004     .03451     .02919
     .02414     .01939     .01495     .01094     .00743     .00473     .00289     .00181
     .00145
.0131     -.0012     -.0204                -.03437    -.04464    -.05253    -.05901    -.06316
    -.06626    -.06966    -.07041    -.06966    -.06749    -.06395    -.05913    -.05332
    -.04663    -.03950    -.03227    -.02538    -.01905    -.01362    -.00932    -.00603
    -.00366    -.00210    -.00122    -.00087    -.00091    -.00109    -.00128    -.00142
    -.00147
F
.0162                .02281     .02973     .03649     .04211     .04799     .05373     .05913
```

```
     .06395    .06818    .07175    .07465    .07688    .07816    .07837    .07758
     .07585    .07314    .06954    .06529    .06053    .05520    .04937    .04305
     .03636    .02956    .02300    .01706    .01201    .00795    .00494    .00300
     .00232
 .0162     .0035    -.0082    -.01872   -.02530   -.03106   -.03663   -.04169
    -.04630   -.05014   -.05312   -.05523   -.05625   -.05633   -.05513   -.05223
    -.04744   -.04124   -.03396   -.02627   -.01883   -.01239   -.00736   -.00371
    -.00127    .00011    .00050    .00034   -.00005   -.00047   -.00084   -.00096
    -.00226
 F
 .0085     .0162     .0242     .0319     .0384     .04378    .04975    .05460
     .05840    .06141    .06384    .06590    .06758    .06878    .06967    .07042
     .07058    .07005    .06863    .06625    .06265    .05775    .05165    .04461
     .03724    .03011    .02353    .01742    .01215    .00791    .00472    .00255
     .00178
 .0085        -.00257   -.01349   -.02385   -.03104   -.03683   -.04184   -.04633
    -.05030   -.05358   -.05603   -.05763   -.05812   -.05729   -.05527   -.05172
    -.04635   -.03965   -.03189   -.02362   -.01586   -.00914   -.00398   -.00061
     .00125    .00211    .00198    .00128    .00024   -.00082   -.00151   -.00178
    -.00180
 F
     .00000    .00346    .00931    .01445    .02056    .02708    .03389    .04034
     .04620    .05120    .05570    .05966    .06314    .06570    .06780    .06903
     .06907    .06817    .06619    .06300    .05855    .05298    .04643    .03889
     .03091    .02334    .01659    .01053    .00490    .00152    .00032    .00009
     .00009
 .0000    -.0161    -.0239    -.0321    -.03875   -.04472   -.04947   -.05325
    -.05658   -.05891   -.06021   -.06049   -.05981   -.05788   -.05459   -.04976
    -.04351   -.03626   -.02856   -.02095   -.01344   -.00733   -.00262    .00066
     .00237    .00188    .00078   -.00024   -.00074   -.00155   -.00117   -.00043
    -.00009
      WING3A INPUT
 $FLOW MACHNO=.8,ALPHAW=-.66, $
 $FLAG    FCR=.TRUE.     , REMESH=.FALSE.    , WBCPRT=.FALSE.
          IDISK=.FALSE.  , $
 ATT WING W3A PLANFORM
0.0        0.0        5.4412     17.365     10.034     11.683
49.838     3.0713     5.8316
          2
          2
0.0        0.0        4.788      3.726
.7782      .7782
          2
4.788      3.726      17.365     10.034
.5016      .5016
          1
          2
0.0        5.441      17.365     11.683
.3595      .3595
          0.     3.7642      .0924      3.3166      .2757      2.0964      .6      .7247
          1.    -.7235
          2
    F     F          INSERT BLANK CARD HERE
          0
          1
    F
FINE SKEWED MESH
 $GPARM MAXIT=400 $
 $XGRID   $
 $YGRID   $
 $ZGRID   $
```

```
COARSE CARTESIAN MESH
 $GPARM    $
 $XGRIDX   NXONX=16 , NXFWDX=6, NXAFTX=8, ALFX=.5, XPLEX=1.5, XPTEX=.25 ,
           ALPXAX=2.0 , $
 $YGRIDX   $
 $ZGRIDX   $
```

A.2 SAMPLE INPUT FOR FPE + CONMIN CODE

```
 $CFLGIN
 F2DBLS=.T.,KOUTBL=3,5,9,15,16*20,K2DBL = 4,OPTM=.T.,
 FFPE=.T.,KOUT=3,5,9,15,20,25*20, $
      CONMIN NAMELIST
 $OPTIN
 NPRINT=5,NV=8,ITMAX=2,NCON=0,NSIDE=0,ICNDIR=0,NSCAL=0,NFDG=0,
 FDCH=.002,FDCHM=.0002,CT=.05,CTL=.001,CTMIN=.01,CTLMIN=.001,
 THETA=1.,PHI=5.,DELFUN=.0001,DABFUN=1.E-06,LINOBJ=0,ITRM=5.VLB=20*-500.,
 VUB=20*500.,ISC=200*0,SSCAL=20*0.,ALPCON=.02,B1CON=4.0,CLDSN=.6,
 ALPHAX=.1,
 ABOBJ1=.1,
 CMDSN=-.1175,OBJCON=.1,ICONCP=1,ICONCL=1,ICONCM=1,ICNTHK=1. $
       KSD      KSURF        KCP         ILE         ITE      NCP1       NCP2        NVT
        4          1          16          64          79        64         69         15
      DESIGN VARIABLES
1.        1.        1.         1.         1.         1.         1.         1.
1.        1.        1.         1.         1.         1.         1.
      DESIGN VARIABLES USED
        1          2           4           5           6          7          8         14
      DESIGN CP VALUES
      -.95       -.95        -.94        -.94        -.94       -.93       -.93       -.92
      -.92       -.91        -.90        -.89        -.88       -.87       -.86       -.85
    ZTEMAX    ZTEMIN
.014        .022
      SECTION ORDINATES
T
        4         33          33
   .000000    .002408    .009607    .021530    .038060    .059039    .084265    .113495
   .146447    .182803    .222215    .264302    .308658    .354858    .402455    .450991
    .50000     .54901     .59754     .64514     .69134     .73570     .77779     .81720
    .85355     .88651     .91573     .94096     .96194     .97847     .99039     .99759
   1.00000
0.        .002408    .009607    .02153     .03806     .059039    .084265    .113495
.146447   .182803    .222215    .264302    .308658    .354858    .402455    .450991
.5        .54901     .59754     .64514     .69134     .7357      .7779      .8172
.85355    .88651     .91573     .94096     .96194     .97847     .99039     .99759
1.
F
0.        .01235     .02066     .02735     .03357     .03978     .04567     .05095
.05547    .05892     .06119     .06232     .06249     .06186     .06061     .05888
.05676    .05428     .05143     .04819     .04454     .04048     .0361      .03158
.02706    .02273     .01868     .01519     .01256     .01049     .009       .0081
.0078
0.        -.02261    -.04028    -.05571    -.06835    -.07846    -.08606    -.09176
-.09577   -.0982     -.09917    -.09894    -.09694    -.09324    -.0883     -.08192
-.07473   -.06688    -.05873    -.05032    -.04225    -.03537    -.02913    -.02353
-.01875   -.01455    -.01143    -.009      -.00758    -.00696    -.00655    -.00653
-.00657
T
F
0.        .00818     .01498     .02091     .02649     .0321      .03789     .04363
.04925    .05458     .05947     .06371     .06715     .06965     .07111     .07145
.07071    .06891     .06632     .06314     .05956     .05561     .05108     .04583
.04001    .03388     .02819     .02316     .019       .01579     .0135      .01206
.01144
0.        -.01324    -.02459    -.03379    -.0408     -.04653    -.05162    -.05622
-.06028   -.06358    -.05601    -.06744    -.06777    -.06697    -.06489     -.06135
-.05607    -.04913   -.04106    -.03266    -.02473    -.01787     -.01252   -.0089
-.00678   -.00538    -.00407    -.00303    -.00271    -.00321    -.00413    -.005
-.00546
F
0.        .00871     .01587     .02163     .02676     .03153     .0362      .04067
.04498    .04908     .05297     .05651     .05965     .06228     .06421     .06547
```

```
.06601     .06573     .06466     .06274     .05994     .05623     .05162     .04626
.04045     .03496     .03005     .02579     .02225     .01949     .01752     .01629
.01582
0.         -.00812    -.01506    -.02068    -.02546    -.02948    -.03314    -.03646
-.03944    -.04208    -.04421    -.04572    -.04646    -.04603    -.04444    -.04146
-.03721    -.0316     -.02484    -.01814    -.01161    -.00602    -.00211    .0006
.00167     .00213     .00203     .0016      -.00002    -.00214    -.00387    -.00491
-.00537
      INITIAL RUN IN FLO22-CONMIN TEST
       FNX        FNY        FNZ      FPLOT      XSCAL      PSCAL      FCONT     FPRINT
      120.        20.        24.         0.         0.         0.         2.         0.
       FIT       COVO        P10        P20        P30      BETA0     STRIP0      FHALF
      100.     .00004        1.7        1.0        1.4        0.1        1.0        0.0
     FMACH         YA         AL        CDO      POWER        RUN
      0.80        0.0        0.0       0.01        1.0        1.0
      ZSYM     SWEEP1     SWEEP2      SWEEP     DIHED1     DIHED2      DIHED
       1.0      37.93     26.658     26.658        0.0        0.0        0.0
      SREF       CREF       XREF        B/2
    1.8971      .5623      1.133      3.374
      ZS/K         XL         YL      CHORD      THICK      ALPHA
       0.0        0.0        0.0    1.06128        1.0      4.015
     .3117     .24288        0.0     .93032        1.0      4.015
     .9302     .72494        0.0     .67043        1.0    3.04874
   3.37392     1.9518        0.0      .3213        1.0    1.02631
```

A.3 SAMPLE INPUT FOR WING-PYLON-NACELLE CODE

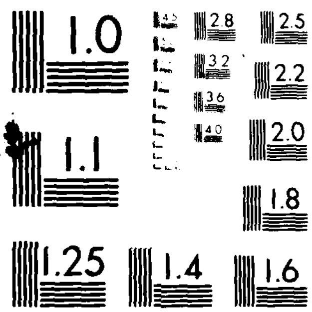
```
 $MASTER
 SAVESOL=.F.,
 NCYCLE=2,
 ITERNAC=10,
 ITERATW=10,
 IPON=.F.,
 $END
 $FLAG
 SCALE=.F.,
 MIN=0.80 ,
 ITERM=10,
 WSB=1.55,
 WSP=.52,
 NESD=1,
 RESTART=.F.,
 ALPHA=-1.1,
 BETA=0.,
 NF=3,
 NA=12,
 NB=2,
 NI=7,
 NE=6,
 NTHET=8,
 ALP=.5,
 NALP=1,
 NF=5,NA=24,NB=4,NE=12,NI=14,
 CHORD=4.58 ,
 NXBODL=17,
 NXBODL=31,
 NF=7,
 NA=25,
 NB=6,
 WSB=1.6,
 NESD=0,
 NCFLAT=3,
 NFLAT=8,
 KSMT=20,
 IFLAT=.F.,
 NSWCH=.F.,
 KSMTS=4,
 SMSLOP=.T.,
 $END
 $STRETCH
 A1=.003,
 A2=2.5,
 A3=.003,
 A4=2.5,
 A1=.05,
 A2=4.,
 A3=.05,
 CR=.35,
 A3R=.1,
 A4R=2.,
 RS=.7801 ,
 $END
0.0         0.0112      0.0224      0.0336      0.0448      0.0673      0.0897      0.1121
0.1345      0.1793      0.2242      0.2446      0.4484      1.3450      2.6900      4.4840
4.5800
0.7801      0.7472      0.7336      0.7235      0.7154      0.7026      0.6928      0.6852
0.6792      0.6711      0.6673      0.6669      0.6669      0.6669      0.6669      0.6669
0.6669
T
T
```

```
T
T
T
T
T
0.0       0.0367    0.0211    0.0379    0.0674    0.1010    0.1431    0.1768
0.2105    0.2442    0.2779    0.3115    0.3452    0.3789    0.4126    0.4384
0.5557    0.6231    0.6904    0.7578    0.8252    0.9864    1.2330    1.6310
2.1300    2.5780    3.0260    3.3630    3.8110    4.2590    4.5800
0.7801    0.7954    0.8061    0.8156    0.8288    0.8412    0.8535    0.8619
0.8695    0.8764    0.8828    0.8887    0.8941    0.8990    0.9035    0.9124
0.9187    0.9236    0.9272    0.9294    0.9303    0.9303    0.9303    0.9303
0.9303    0.9303    0.9303    0.9144    0.8469    0.7467    0.5669
T
T
T
T
T
T
T
 ADVANCED TRANSONIC TECHNOLOGY WING W3A
 $FLOW MACHNO=.795,ALPHAW=-1.1,$
 $FLAG FCR=.F.,EXTMSH=.F.,WBCPRT=.F.,IDISK=.F.,AFIN=.T.,REMESH=.F.,
 ISAVE=.T.,$
      WING PLANFORM
0.0       0.0       5.441     17.365    10.034    11.683
49.838    3.0713    5.8316
          2
          2
0.0       0.0       4.788     3.726
.7782     .7782
          2
4.788     3.726     17.365    10.034
.5016     .5016
          1
          2
0.0       5.4412    17.365    11.683
.3595     .3595
 ATT FLUID WING
          5        33         33          0
0.        3.7642    .0924     3.3166    .2757     2.0964    .6        .7247
1.        -.7235
0.00000   .002410   .009610   .021530   .038060   .05904    .084270   .113490
.146450   .182800   .22221    .26430    .308660   .354860   .402450   .45099
.5000     .549010   .59755    .645140   .69134    .7357000  .77779    .81720
.85355    .886510   .91573    .940960   .961940   .978470   .990390   .997590
1.000
0.0000    .002408   .009607   .021530   .038060   .059039   .084265   .113495
.146447   .182803   .222215   .264302   .308658   .354858   .402455   .450991
.5000     .549009   .597545   .645142   .691342   .735698   .777785   .817197
.353553   .886505   .915735   .940961   .961940   .978470   .990393   .997592
1.000
F
.0179     .0322               .04282    .05139    .05839    .06441    .06971    .07390
    .07702    .07950    .08109    .08120    .07996    .07751    .07440    .07066
    .06637    .06153    .05543    .05105    .04544    .03976    .03422    .02891
    .02388    .01913    .01466    .01063    .00728    .00451    .00242    .00111
    .00066
.0179     -.0001    -.0172    -.0316    -.0434    -.05188   -.05833   -.06355
   -.06717   -.06942   -.07011   -.06953   -.06743   -.06403   -.05948   -.05380
   -.04739   -.04056   -.03341   -.02642   -.02003   -.01460   -.01057   -.00730
   -.00474   -.00296   -.00191   -.00155   -.00141   -.00104   -.00089   -.00082
   -.00067
F
```

AD-A110 232 LOCKHEED-GEORGIA CO MARIETTA F/G 1/3
NUMERICAL AIRCRAFT DESIGN USING 3-D TRANSONIC ANALYSIS WITH OPT--ETC(U)
AUG 81 R A WEED, A J SROKOWSKI F33615-78-C-3014
UNCLASSIFIED LG81ER0107-VOL-3-PT-1 AFWAL-TR-81-3091-VOL-3-PT- NL

2 of 2
AD
A110232

END
DATE
FILMED
2 82
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

```
.0131       .0306       .0434       .0512       .0579                   .06377      .06931      .07359
     .07695      .07937      .08059      .08049      .07918      .07698      .07401      .07041
     .06625      .06160      .05557      .05122      .04566      .04004      .03451      .02919
     .02414      .01939      .01455      .01094      .00743      .00473      .00289      .00181
     .00145
.0131       -.0012      -.0204                  -.03437     -.04464     -.05253     -.05901     -.06316
    -.06626     -.06966     -.07041     -.06966     -.06749     -.06395     -.05913     -.05332
    -.04663     -.03950     -.03227     -.02538     -.01905     -.01362     -.00932     -.00603
    -.00366     -.00210     -.00122     -.00087     -.00091     -.00109     -.00128     -.00142
    -.00147
F
.0162                    .02281      .02573      .03649      .04211      .04799      .05373      .05913
     .06395      .06818      .07175      .07465      .07688      .07816      .07837      .07758
     .07585      .07314      .06954      .06529      .06053      .05520      .04937      .04305
     .03638      .02956      .02300      .01706      .01201      .00795      .00494      .00300
     .00232
.0162       .0035       -.0082                  -.01872     -.02530     -.03106     -.03663     -.04169
    -.04630     -.05014     -.05312     -.05523     -.05625     -.05633     -.05513     -.05223
    -.04744     -.04124     -.03396     -.02627     -.01883     -.01239     -.00736     -.00371
    -.00127      .00011      .00050      .00034     -.00005     -.00047     -.00084     -.00098
    -.00226
F
.0085       .0162       .0242       .0319       .0384                   .04378      .04975      .05460
     .05840      .06141      .06384      .06590      .06758      .06878      .06967      .07042
     .07058      .07005      .06863      .06625      .06265      .05775      .05165      .04461
     .03724      .03011      .02353      .01742      .01215      .00791      .00472      .00255
     .00178
.0085                   -.00257     -.01349     -.02385     -.03104     -.03683     -.04184     -.04633
    -.05030     -.05358     -.05503     -.05763     -.05812     -.05729     -.05527     -.05172
    -.04635     -.03965     -.03189     -.02362     -.01586     -.00914     -.00398     -.00061
     .00125      .00211      .00198      .00128      .00024     -.00082     -.00151     -.00178
    -.00180
F
     .00000      .00346      .00931      .01445      .02056      .02708      .03389      .04034
     .04620      .05120      .05570      .05966      .06314      .06570      .06780      .06903
     .06907      .06817      .06619      .06300      .05855      .05298      .04643      .03889
     .03091      .02334      .01659      .01053      .00490      .00152      .00032      .00009
     .00009
.0000       -.0161      -.0239      -.0321                  -.03875     -.04472     -.04947     -.05325
    -.05658     -.05891     -.06021     -.06049     -.05981     -.05788     -.05459     -.04976
    -.04351     -.03626     -.02856     -.02095     -.01344     -.00733     -.00262      .00066
     .00237      .00188      .00078     -.00024     -.00074     -.00155     -.00117     -.00043
    -.00009
 T
5.358       0.0
           2
-3.95       -.9699      -2.23       -.4
-2.23       -.4         .675        0.0
           2
0.6         -.85        2.83        -.275
2.83        -.275       2.99        0.0
          30
0.0         .0024       .0095       .0213       .0377       .0585       .0933       .1124
.1450       .1810       .2200       .2617       .3056       .3513       .3965       .4464
.4950       .5436       .5916       .6388       .6845       .7284       .7700       .8091
.9451       .8777       .9067       .9524       .9877       1.0
0.0         .006        .0118       .0172       .0222       .0268       .0309       .0344
.0373       .0396       .0412       .0423       .0428       .0429       .0427       .0419
.0408       .0392       .0372       .0347       .0320       .0289       .0256       .0223
.0188       .0154       .0122       .0068       .0022       .0006
0.0         -.006       -.0118      -.0172      -.0222      -.0268      -.0309      -.0344
-.0373      -.0396      -.0412      -.0423      -.0428      -.0429      -.0427      -.0419
-.0408      -.0392      -.0372      -.0347      -.0320      -.0289      -.0256      -.0223
-.0188      -.0154      -.0122      -.0068      -.0022      -.0006
```

```
-1.75      -3.95
            2
    F       F
            Ø
            1
    F
FINE SKEWED
$GPARM        KMAX=27,NACGEN=.T.,KTIP=23,YMRD=.F.,ZMRD=.F.,XMRD=.F.,
MAXIT=1Ø ,JMAX=54,LMAX=2Ø,LWINGU=12,$
```

A.4 SAMPLE INPUT FOR TWODBL PROGRAM

```
ATT W3 CL UPPER
1.4        1714.87   8186.     498.      .80
   38    0    5    7    0    2    0    0    1   1.7
0.0      0.0      0.0      0.0
    1    0    0    0    1    0
    1   33 .4534
ATT W3 CL LOWER
1.4        1714.87   8186.     498.      .80
   38    0    5    7    0    2    0    0    1   1.7
0.0      0.0      0.0      0.0
    1    0    0    0    1    0
    0   33 .4534
ATT W3 ROOT UPPER
1.4        1714.87   8186.     498.      .80
   38    0    5    7    0    2    0    0    1   1.7
0.0      0.0      0.0      0.0
    1    0    0    0    1    0
    0   33 .3837
ATT W3 ROOT LOWER
1.4        1714.87   8186.     498.      .80
   38    0    5    7    0    2    0    0    1   1.7
0.0      0.0      0.0      0.0
    1    0    0    0    1    0
    0   33 .3837
ATT W3 BREAK UPPER
1.4        1714.87   8186.     498.      .80
   38    0    5    7    0    2    0    0    1   1.7
0.0      0.0      0.0      0.0
    1    0    0    0    1    0
    0   33 .2847
ATT W3 BREAK LOWER
1.4        1714.87   8186.     498.      .80
   38    0    5    7    0    2    0    0    1   1.7
0.0      0.0      0.0      0.0
    1    0    0    0    1    0
    0   33 .2947
ATT W3 ETA= .6 UPPER
1.4        1714.87   8186.     498.      .80
   38    0    5    7    0    2    0    0    1   1.7
0.0      0.0      0.0      0.0
    1    0    0    0    1    0
    0   33 .2235
ATT W3 ETA= .6 LOWER
1.4        1714.87   8186.     498.      .80
   38    0    5    7    0    2    0    0    1   1.7
0.0      0.0      0.0      0.0
    1    0    0    0    1    0
    0   33 .2235
ATT W3 ETA=.85 UPPER
1.4        1714.87   8186.     498.      .80
   38    0    5    7    0    2    0    0    1   1.7
0.0      0.0      0.0      0.0
    1    0    0    0    1    0
    0   33 .1666
ATT W3 ETA=.85 LOWER
1.4        1714.87   8186.     498.      .80
   38    0    5    7    0    2    0    0    1   1.7
0.0      0.0      0.0      0.0
    1    0    0    0    1    0
    0   33 .1666
```

APPENDIX B

SAMPLE OUTPUT

B.1 SAMPLE OUTPUT FOR ESD + CONMIN CODE

ESD GRID AND GEOMETRY INFORMATION

COMPUTATIONAL GRID

N	XI	ETA	ZT	DX	DY	DZ	D2X	D2Y	D2Z
1	-.50000	0.00000	-1.99993	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	-.36099	.07145	-.89002	.1242	.0787	.7228	-.0296	.0144	-.7741
3	-.25159	.15731	-.55424	.0965	.0924	.2518	-.0259	.0132	-.1679
4	-.16808	.25632	-.38639	.0724	.1050	.1362	-.0222	.0119	-.0633
5	-.10676	.36724	-.28186	.0521	.1162	.0894	-.0185	.0106	-.0303
6	-.06392	.48881	-.20764	.0354	.1263	.0660	-.0148	.0094	-.0165
7	-.03587	.61977	-.14990	.0225	.1350	.0530	-.0111	.0081	-.0096
8	-.01891	.75888	-.10172	.0133	.1426	.0454	-.0074	.0069	-.0056
9	-.00933	.90488	-.05909	.0077	.1488	.0412	-.0037	.0056	-.0029
10	-.00345	1.05652	-.01939	.0064	.1538	.0392	.0010	.0044	-.0009
11	.00345	1.21254	.01939	.0085	.1576	.0392	.0032	.0031	.0009
12	.01352	1.37169	.05909	.0116	.1601	.0412	.0030	.0019	.0029
13	.02657	1.53273	.10172	.0145	.1613	.0454	.0028	.0006	.0056
14	.04243	1.69439	.14990	.0172	.1613	.0530	.0026	-.0006	.0096
15	.06093	1.85542	.20764	.0197	.1601	.0660	.0025	-.0019	.0165
16	.08189	2.01458	.28186	.0221	.1576	.0894	.0023	-.0031	.0303
17	.10514	2.17060	.38639	.0243	.1538	.1362	.0021	-.0044	.0633
18	.13049	2.32224	.55424	.0263	.1488	.2518	.0019	-.0056	.1679
19	.15778	2.46824	.89002	.0282	.1426	.7228	.0018	-.0069	.7741
20	.18682	2.60735	1.99993	.0298	.1350	0.0000	.0016	-.0081	0.0000
21	.21744	2.73831	0.00000	.0313	.1263	0.0000	.0014	-.0094	0.0000
22	.24947	2.85988	0.00000	.0326	.1162	0.0000	.0012	-.0106	0.0000
23	.28273	2.97079	0.00000	.0338	.1050	0.0000	.0011	-.0119	0.0000
24	.31704	3.06981	0.00000	.0348	.0924	0.0000	.0009	-.0132	0.0000
25	.35224	3.15567	0.00000	.0355	.0787	0.0000	.0007	-.0144	0.0000
26	.38813	3.22712	0.00000	.0362	.0716	0.0000	.0005	.0003	0.0000
27	.42455	3.29886	0.00000	.0366	.0955	0.0000	.0004	.0475	0.0000
28	.46133	3.41811	0.00000	.0369	.1668	0.0000	.0002	.0950	0.0000
29	.49827	3.63238	0.00000	.0369	.2856	0.0000	-.0000	.1426	0.0000
30	.53522	3.98924	0.00000	.0369	0.0000	0.0000	-.0002	0.0000	0.0000
31	.57200	0.00000	0.00000	.0366	0.0000	0.0000	-.0004	0.0000	0.0000
32	.60842	0.00000	0.00000	.0362	0.0000	0.0000	-.0005	0.0000	0.0000
33	.64431	0.00000	0.00000	.0355	0.0000	0.0000	-.0007	0.0000	0.0000
34	.67951	0.00000	0.00000	.0348	0.0000	0.0000	-.0009	0.0000	0.0000
35	.71382	0.00000	0.00000	.0338	0.0000	0.0000	-.0011	0.0000	0.0000
36	.74708	0.00000	0.00000	.0326	0.0000	0.0000	-.0012	0.0000	0.0000
37	.77911	0.00000	0.00000	.0313	0.0000	0.0000	-.0014	0.0000	0.0000
38	.80973	0.00000	0.00000	.0298	0.0000	0.0000	-.0016	0.0000	0.0000
39	.83877	0.00000	0.00000	.0282	0.0000	0.0000	-.0018	0.0000	0.0000
40	.86606	0.00000	0.00000	.0263	0.0000	0.0000	-.0019	0.0000	0.0000
41	.89141	0.00000	0.00000	.0243	0.0000	0.0000	-.0021	0.0000	0.0000
42	.91465	0.00000	0.00000	.0221	0.0000	0.0000	-.0023	0.0000	0.0000
43	.93561	0.00000	0.00000	.0197	0.0000	0.0000	-.0025	0.0000	0.0000
44	.95411	0.00000	0.00000	.0172	0.0000	0.0000	-.0026	0.0000	0.0000
45	.96998	0.00000	0.00000	.0145	0.0000	0.0000	-.0028	0.0000	0.0000
46	.98303	0.00000	0.00000	.0116	0.0000	0.0000	-.0030	0.0000	0.0000
47	.99310	0.00000	0.00000	.0085	0.0000	0.0000	-.0032	0.0000	0.0000
48	1.00000	0.00000	0.00000	.0072	0.0000	0.0000	.0005	0.0000	0.0000
49	1.00743	0.00000	0.00000	.0139	0.0000	0.0000	.0130	0.0000	0.0000
50	1.02787	0.00000	0.00000	.0335	0.0000	0.0000	.0260	0.0000	0.0000
51	1.07434	0.00000	0.00000	.0660	0.0000	0.0000	.0390	0.0000	0.0000
52	1.15984	0.00000	0.00000	.1115	0.0000	0.0000	.0520	0.0000	0.0000
53	1.29739	0.00000	0.00000	.1701	0.0000	0.0000	.0651	0.0000	0.0000
54	1.50000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

UPSTREAM AND DOWNSTREAM BOUNDARY LOCATION

K	ETA	XUP	XDOWN	XIY(UP)	XIY(DN)
1	0.000000	-.499982	1.499945	-.987586	-.150156
2	.071450	-.429421	1.510673	-1.018043	-.154779
3	.157308	-.344632	1.523563	-1.057223	-.160727
4	.256323	-.246850	1.538428	-1.106327	-.168181
5	.367240	-.137314	1.555079	-1.167049	-.177400
6	.488807	-.017260	1.573328	-1.241750	-.188742
7	.619771	.112075	1.592986	-1.333721	-.202706
8	.758879	.249453	1.613864	-1.447610	-.219999
9	.904878	.383296	1.639223	-.911949	-.459224
10	1.056516	.470133	1.682952	-.944322	-.475550
11	1.212538	.559477	1.727945	-.980128	-.493605
12	1.371693	.650611	1.773843	-1.019568	-.513489
13	1.532728	.742819	1.820283	-1.062849	-.535308
14	1.694389	.835384	1.866904	-1.110165	-.559158
15	1.855423	.927588	1.913345	-1.161688	-.585125
16	2.014578	1.018715	1.959245	-1.217542	-.613272
17	2.170601	1.108049	2.004243	-1.277774	-.643623
18	2.322238	1.194871	2.047976	-1.342320	-.676145
19	2.468237	1.278467	2.090084	-1.410949	-.710721
20	2.607346	1.358117	2.130206	-1.483208	-.747122
21	2.738310	1.433106	2.167979	-1.558349	-.784973
22	2.859877	1.502715	2.203043	-1.635253	-.823710
23	2.970794	1.566228	2.235036	-1.712359	-.862546
24	3.069808	1.622926	2.263595	-1.787606	-.900445
25	3.155667	1.672092	2.288361	-1.858423	-.936111
26	3.227117	1.713007	2.308971	-1.921763	-.968013
27	3.298861	1.754092	2.329665	-1.989842	-1.002305
28	3.418110	1.822380	2.364063	-2.114336	-1.065014
29	3.632383	1.945083	2.425870	-2.382138	-1.199909
30	3.989240	2.149437	2.528805	-3.018969	-1.520687

WING DESCRIPTION

L.E. SWEEP	T.E. SWEEP	ROOT CHORD	TIP CHORD	WING AREA,	ASPECT RATIO	TAPER RATIO	REF CHORD
.5778	.3594	1.0000	.3031	1.685	12.0859	.3031	.5298

WING LEADING AND TRAILING EDGE COORDINATES

K NOMINAL	ETA WING ROOT	XLEW	XTEW
1	0.000000	0.000000	.999963
2	.071450	.055602	1.025649
3	.157308	.122417	1.056515
4	.256323	.199469	1.092109
5	.367240	.285785	1.131981
6	.488807	.380387	1.175681
7	.619771	.482303	1.222758
8	.758879	.590556	1.272761
9	.904878	.697278	1.325241
10	1.056516	.773337	1.379747
11	1.212538	.851594	1.435828
12	1.371693	.931419	1.493035
13	1.532728	1.012185	1.550917
14	1.694389	1.093264	1.609024
15	1.855423	1.174027	1.666906
16	2.014578	1.253848	1.724113
17	2.170601	1.332097	1.780194
18	2.322238	1.408148	1.834700
19	2.468237	1.481371	1.887180
20	2.607346	1.551139	1.937184
21	2.738310	1.616824	1.984261
22	2.859877	1.677797	2.027961
23	2.970794	1.733430	2.067834
24	3.069808	1.783093	2.103428
25	3.155667	1.826159	2.134294

XI=0 AND XI=1 COORDINATES AND SLOPES

K NOMINAL	ETA WING ROOT	XLE	XTE	XLEP	XTEP
1	0.000000	0.000000	.999963	.778200	.359500
2	.071450	.055602	1.025649	.778198	.359495
3	.157308	.122417	1.056515	.778196	.359488
4	.256323	.199469	1.092109	.778194	.359482
5	.367240	.285785	1.131981	.778193	.359475
6	.488807	.380387	1.175681	.778193	.359468
7	.619771	.482303	1.222758	.778194	.359461
8	.758879	.590556	1.272761	.778197	.359455
9	.904878	.697278	1.325241	.501597	.359450
10	1.056516	.773337	1.379747	.501579	.359445
11	1.212538	.851594	1.435828	.501563	.359442
12	1.371693	.931419	1.493035	.501550	.359439
13	1.532728	1.012185	1.550917	.501540	.359438
14	1.694389	1.093264	1.609024	.501532	.359438
15	1.855423	1.174027	1.666906	.501527	.359440
16	2.014578	1.253848	1.724113	.501526	.359442
17	2.170601	1.332097	1.780194	.501527	.359446
18	2.322238	1.408148	1.834700	.501530	.359451
19	2.468237	1.481371	1.887180	.501536	.359457
20	2.607346	1.551139	1.937184	.501544	.359463
21	2.738310	1.616824	1.984261	.501553	.359470

22	2.859877	1.677797	2.027961	.501563	.359477
23	2.970794	1.733430	2.067834	.501574	.359484
24	3.069808	1.783093	2.103428	.501585	.359491
25	3.155667	1.826159	2.134294	.501595	.359497
NOMINAL WING TIP					
26	3.227117	1.861998	2.159980	.501600	.359500
27	3.298861	1.897985	2.185772	.501600	.359500
28	3.418110	1.957800	2.228642	.501600	.359500
29	3.632383	2.065280	2.305673	.501600	.359500
30	3.989240	2.244279	2.433963	.501600	.359500

J INDEX OF LEADING AND TRAILING EDGE POINTS AND DX/C

K	ETA	JLE	JTE	(X-XLEW)/C	(X-XTEW)/C
NOMINAL WING ROOT					
1	0.000000	11	48	.003452	1.000000
2	.071450	11	48	.003452	1.000000
3	.157308	11	48	.003452	1.000000
4	.256323	11	48	.003452	1.000000
5	.367240	11	48	.003452	1.000000
6	.488807	11	48	.003452	1.000000
7	.619771	11	48	.003452	1.000000
8	.758879	11	48	.003452	1.000000
9	.904878	11	48	.003452	1.000000
10	1.056516	11	48	.003452	1.000000
11	1.212538	11	48	.003452	1.000000
12	1.371693	11	48	.003452	1.000000
13	1.532728	11	48	.003452	1.000000
14	1.694389	11	48	.003452	1.000000
15	1.855423	11	48	.003452	1.000000
16	2.014578	11	48	.003452	1.000000
17	2.170601	11	48	.003452	1.000000
18	2.322238	11	48	.003452	1.000000
19	2.468237	11	48	.003452	1.000000
20	2.607346	11	48	.003452	1.000000
21	2.738310	11	48	.003452	1.000000
22	2.859877	11	48	.003452	1.000000
23	2.970794	11	48	.003452	1.000000
24	3.069808	11	48	.003452	1.000000
25	3.155667	11	48	.003452	1.000000

COARSE CARTESIAN MESH

MAXITN	MAXITX	INCRX
1	1	1

RSUB	EPS
1.7000	.100E+01

XMRD	YMRD	ZMRD
F	F	F

NXONX	NXFWDX	NXAFTX	ALPXFX	ALPXAX	ALFX	XPLEX	XPTEX
16	6	8	5.0000	2.0000	.5000	1.5000	.2500

NYONX	NYOFFX	ALPYX	YPTIPX	ALFPX
10	5	1.0000	.5000	1.0000

NZX	ALPZX	ZPX
20	5.0000	.5000

COMPUTATIONAL GRID

N	XIEX	ETAX	ZTX
1	-10.73608	0.00000	-10.73568
2	-5.81255	.20715	-7.23850
3	-2.75474	.49586	-5.28494
4	-1.09300	.84575	-4.00083
5	-.36123	1.23642	-3.06431
6	-.09431	1.64748	-2.32830
7	.09431	2.05854	-1.71518
8	.28060	2.44922	-1.17918
9	.46366	2.79910	-.69045
10	.64254	3.08782	-.22743
11	.81631	3.29497	.22743
12	.98406	3.49245	.69045
13	1.14484	3.91778	1.17918
14	1.29772	4.80112	1.71518
15	1.44179	6.38278	2.32830
16	1.57610	0.00000	3.06431
17	1.69973	0.00000	4.00083
18	1.81175	0.00000	5.28494
19	1.91123	0.00000	7.23850
20	1.99723	0.00000	10.73568
21	2.06884	0.00000	0.00000
22	2.12512	0.00000	0.00000
23	2.16513	0.00000	0.00000
24	2.20847	0.00000	0.00000
25	2.32236	0.00000	0.00000
26	2.57743	0.00000	0.00000
27	3.04442	0.00000	0.00000
28	3.79465	0.00000	0.00000
29	4.90116	0.00000	0.00000
30	6.44165	0.00000	0.00000

J INDEX OF LEADING AND TRAILING EDGE POINTS AND X LOCATIONS

K	ETAX	JLEX	JTEX	XLEWX	XTEWX
1	0.000000	7	12	0.000000	.999963
2	.207149	8	12	.161203	1.074432
3	.495863	9	13	.385878	1.178218
4	.845751	11	14	.658160	1.303988
5	1.236421	12	15	.863573	1.444413
6	1.647483	13	16	1.069739	1.592164
7	2.058545	14	17	1.275898	1.739916
8	2.449215	16	18	1.471831	1.880342
9	2.799103	17	20	1.647315	2.006114
10	3.087817	18	21	1.792126	2.109902

ESD RESTART DATA

```
PARAMETERS FROM OLD SOLUTION

  ITERO     JMO      KMO      LMO      LWUO     KTO
   400       30       15       20       11       11

  XIO(J),J=1,JMO
-10.73608  -5.81255  -2.75474  -1.09300   -.36123   -.09431    .09431    .28060
   .46366    .64254    .81631    .98406   1.14484   1.29772   1.44179   1.57610
  1.69973   1.81175   1.91123   1.99723   2.06884   2.12512   2.16513   2.20847
  2.32236   2.57743   3.04442   3.79465   4.90116   6.44165

  ETAO(K),K=1,KMO
  0.00000    .20715    .49586    .84575   1.23642   1.64748   2.05854   2.44922
  2.79910   3.08782   3.29497   3.49245   3.91778   4.80112   6.38278

  ZTO(L),L=1,LMO
-10.73568  -7.23850  -5.28494  -4.00083  -3.06431  -2.32830  -1.71518  -1.17918
  -.69045   -.22743    .22743    .69045   1.17918   1.71518   2.32830   3.06431
  4.00083   5.28494   7.23850  10.73568

           PERTURBED CONTROL STATION ORDINATES

  MOD WING UPPER SURFACE ORDS
     .00850    .01325    .02189    .03019    .03728    .04351    .04921    .05424    .05837    .06169
     .06440    .06665    .06851    .06998    .07112    .07188    .07209    .07156    .07014    .06771
     .06419    .05958    .05403    .04792    .04170    .03579    .03035    .02546    .02129    .01798
     .01560    .01416    .01367

  MOD WING LOWER SURFACE ORDS
     .00850    .00178   -.01017   -.02105   -.02950   -.03604   -.04144   -.04614   -.05021   -.05359
    -.05617   -.05782   -.05838   -.05774   -.05578   -.05237   -.04749   -.04136   -.03442   -.02728
    -.02060   -.01492   -.01055   -.00753   -.00572   -.00490   -.00492   -.00554   -.00646   -.00736
    -.00800   -.00831   -.00838

  TWIST
    3.76420   3.31660   2.09640    .72470   -.72350
```

ESD ITERATION CONVERGENCE INFORMATION

ITERATION HISTORY

ITER	DPHI	J	K	L	NSUP	DPJMAX	KJ	DPHIX	JX	KX	LX	CLG
401	.18796E-02	46	4	11	1520	.14411E-04	26	.66723E-03	29	4	10	.61500
402	.13053E-02	48	5	11	1506	.13506E-05	26	.62147E-03	29	3	10	.61168
403	.10521E-02	48	5	11	1495	.77329E-06	27	.50395E-03	29	1	10	.60924
404	.88530E-03	47	5	11	1482	.40660E-04	25	.45482E-03	29	1	10	.60734
405	.77261E-03	47	6	11	1478	.62940E-04	25	.38288E-03	29	1	11	.60577
406	.68608E-03	47	6	11	1470	.58943E-04	25	.34021E-03	25	3	11	.60437
407	.61859E-03	47	5	11	1462	.47531E-04	25	.31607E-03	24	3	11	.60305
408	.70688E-03	36	19	11	1455	.35513E-04	25	.30524E-03	24	3	11	.60180
409	.54150E-03	47	5	12	1455	.25674E-04	25	.29681E-03	24	3	11	.60063
410	.51555E-03	47	6	12	1450	.17588E-04	25	.28978E-03	24	3	11	.59952

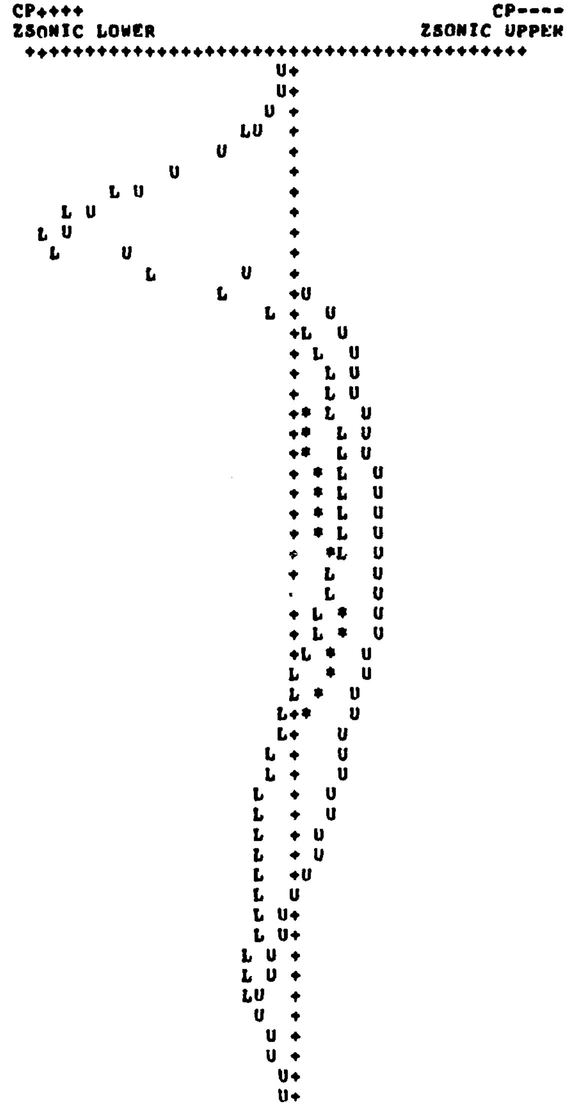
POTENTIAL JUMP AT TRAILING EDGE

.1990E+00	.2001E+00	.2008E+00	.2013E+00	.2030E+00	.2058E+00
.2084E+00	.2104E+00	.2108E+00	.2066E+00	.2001E+00	.1917E+00
.1820E+00	.1713E+00	.1599E+00	.1483E+00	.1364E+00	.1244E+00
.1124E+00	.1005E+00	.8862E-01	.7673E-01	.6454E-01	.5098E-01
.3272E-01					

ESD CONVERGED SOLUTION INFORMATION

ETA/SSPAN =0.0000

J	X/C	CPU	CPL	MU	ML	ZSONICU	ZSONICL
2	-.36099	.05273	.04786	.773	.775	0.000	0.000
3	-.25159	.10925	.10881	.742	.743	0.000	0.000
4	-.16808	.18985	.19024	.697	.697	0.000	0.000
5	-.10676	.32262	.32721	.615	.612	0.000	0.000
6	-.06392	.55503	.57899	.435	.412	0.000	0.000
7	-.03587	.89004	.95836	.032	.032	0.000	0.000
8	-.01891	1.24503	1.37043	.032	.032	0.000	0.000
9	-.00933	1.53762	1.71233	.032	.032	0.000	0.000
10	-.00345	1.77472	1.98981	.032	.032	0.000	0.000
11	.00345	1.27007	1.82851	.032	.032	0.000	0.000
12	.01352	.38724	1.15292	.571	.032	0.000	0.000
13	.02657	-.05714	.55827	.828	.432	0.000	0.000
14	.04243	-.28631	.17101	.934	.708	0.000	0.000
15	.06093	-.39674	-.06500	.981	.832	0.000	0.000
16	.08189	-.46352	-.17582	1.008	.885	0.000	0.000
17	.10514	-.48657	-.24404	1.017	.916	0.000	0.000
18	.13049	-.50756	-.27941	1.026	.931	0.000	0.000
19	.15778	-.52216	-.31059	1.032	.945	.059	0.000
20	.18682	-.54899	-.33610	1.042	.955	.059	0.000
21	.21744	-.58697	-.35759	1.057	.965	.102	0.000
22	.24947	-.62597	-.37477	1.072	.972	.150	0.000
23	.28273	-.65666	-.38431	1.083	.976	.150	0.000
24	.31704	-.67482	-.38395	1.090	.976	.208	0.000
25	.35224	-.68067	-.37291	1.092	.971	.208	0.000
26	.38813	-.67748	-.35000	1.091	.961	.282	0.000
27	.42455	-.66956	-.31518	1.088	.947	.282	0.000
28	.46133	-.65854	-.27063	1.084	.927	.282	0.000
29	.49827	-.64276	-.21896	1.078	.904	.386	0.000
30	.53522	-.61903	-.16178	1.069	.878	.386	0.000
31	.57200	-.58583	-.10022	1.056	.849	.282	0.000
32	.60842	-.54518	-.03589	1.041	.818	.282	0.000
33	.64431	-.50018	.02801	1.023	.786	.208	0.000
34	.67951	-.45475	.08733	1.005	.754	.059	0.000
35	.71382	-.41345	.13812	.988	.727	0.000	0.000
36	.74708	-.37477	.17813	.972	.704	0.000	0.000
37	.77911	-.33622	.20853	.956	.686	0.000	0.000
38	.80973	-.29815	.23260	.939	.672	0.000	0.000
39	.83877	-.25752	.25332	.921	.659	0.000	0.000
40	.86606	-.20901	.27160	.900	.648	0.000	0.000
41	.89141	-.14874	.28575	.872	.639	0.000	0.000
42	.91465	-.08023	.29368	.840	.634	0.000	0.000
43	.93561	-.01260	.29704	.806	.631	0.000	0.000
44	.95411	.04832	.30212	.775	.628	0.000	0.000
45	.96998	.10398	.31311	.745	.621	0.000	0.000
46	.98303	.15852	.32481	.715	.613	0.000	0.000
47	.99310	.21429	.32878	.683	.611	0.000	0.000
48	1.00000	.25935	.32733	.655	.612	0.000	0.000
49	1.00743	.24847	.29117	.662	.635	0.000	0.000
50	1.02787	.19740	.21916	.693	.680	0.000	0.000
51	1.07434	.14967	.15466	.720	.717	0.000	0.000
52	1.15984	.10559	.10637	.744	.744	0.000	0.000
53	1.29739	.06743	.06545	.765	.766	0.000	0.000



FORCE DATA

REFERENCE AREA = 1.685
REFERENCE CHORD = .5298
MOMENT ORIGIN = 1.0675

SPANWISE FORCE DISTRIBUTIONS

K	ETA/SSPAN	C/CREF	CN*C/CREF	CA*C/CREF
1	0.00000	.18874E+01	.73822E+00	.24287E+00
2	.02239	.18309E+01	.72982E+00	.11795E+00
3	.04929	.17631E+01	.73097E+00	.72426E-01
4	.08032	.16848E+01	.73338E+00	.44100E-01
5	.11507	.15972E+01	.73938E+00	.20162E-01
6	.15316	.15011E+01	.74768E+00	.29362E-02
7	.19420	.13976E+01	.75463E+00	-.62057E-02
8	.23779	.12876E+01	.75789E+00	-.11224E-01
9	.28354	.11853E+01	.76235E+00	-.11070E-01
10	.33105	.11446E+01	.74795E+00	-.35967E-02
11	.37994	.11027E+01	.72425E+00	-.14155E-02
12	.42981	.10600E+01	.69372E+00	-.93437E-03
13	.48027	.10168E+01	.65798E+00	-.85709E-03
14	.53092	.97348E+00	.61866E+00	-.55937E-03
15	.58138	.93029E+00	.57724E+00	-.65418E-04
16	.63125	.88761E+00	.53384E+00	.19081E-04
17	.68014	.84577E+00	.48916E+00	-.19383E-03
18	.72766	.80511E+00	.44422E+00	-.20415E-03
19	.77340	.76595E+00	.39919E+00	.18832E-03
20	.81699	.72865E+00	.35517E+00	.29717E-03
21	.85803	.69353E+00	.31147E+00	.20212E-03
22	.89612	.66092E+00	.26798E+00	-.41617E-03
23	.93088	.63118E+00	.22352E+00	-.18361E-02
24	.96190	.60462E+00	.17378E+00	-.47265E-02
25	.98881	.58160E+00	.10709E+00	-.11300E-01

K	ETA/SSPAN	CN*(C/CREF)**2	CL*C/CREF	CD*C/CREF	CL
1	0.00000	.74949E+00	.72418E+00	.28557E+00	.38369
2	.02239	.71231E+00	.72320E+00	.15892E+00	.39499
3	.04929	.67752E+00	.72706E+00	.11185E+00	.41238
4	.08032	.62793E+00	.73112E+00	.81631E-01	.43394
5	.11507	.55895E+00	.73841E+00	.55700E-01	.46232
6	.15316	.46996E+00	.74755E+00	.36151E-01	.49801
7	.19420	.36384E+00	.75488E+00	.23935E-01	.54013
8	.23779	.24573E+00	.75828E+00	.14842E-01	.58889
9	.28354	.12638E+00	.76266E+00	.10497E-01	.64345
10	.33105	.24421E-01	.74804E+00	.15455E-01	.65355
11	.37994	-.72623E-01	.72428E+00	.14775E-01	.65681
12	.42981	-.16287E+00	.69374E+00	.12192E-01	.65445
13	.48027	-.24429E+00	.65799E+00	.91144E-02	.64710
14	.53092	-.31547E+00	.61866E+00	.62690E-02	.63551
15	.58138	-.37508E+00	.57724E+00	.37184E-02	.62050
16	.63125	-.42054E+00	.53384E+00	.18991E-02	.60143
17	.68014	-.45092E+00	.48916E+00	.47596E-03	.57836
18	.72766	-.46726E+00	.44422E+00	-.62035E-03	.55176
19	.77340	-.47036E+00	.39919E+00	-.11644E-02	.52117
20	.81699	-.46116E+00	.35517E+00	-.18232E-02	.48744
21	.85803	[illegible]	[illegible]	[illegible]	[illegible]

22	.89612	-.40705E+00	.26798E+00	-.34712E-02	.40546
23	.93088	-.36158E+00	.22349E+00	-.49997E-02	.35409
24	.96190	-.29706E+00	.17370E+00	-.76531E-02	.28728
25	.98881	-.19197E+00	.10687E+00	-.13374E-01	.18376

WING FORCE COEFFICIENTS

CN = .57235E+00

CA = .75028E-02

CM = -.83658E-01

CL = .57186E+00 INTEGRATION
     .59952E+00 CIRCULATION

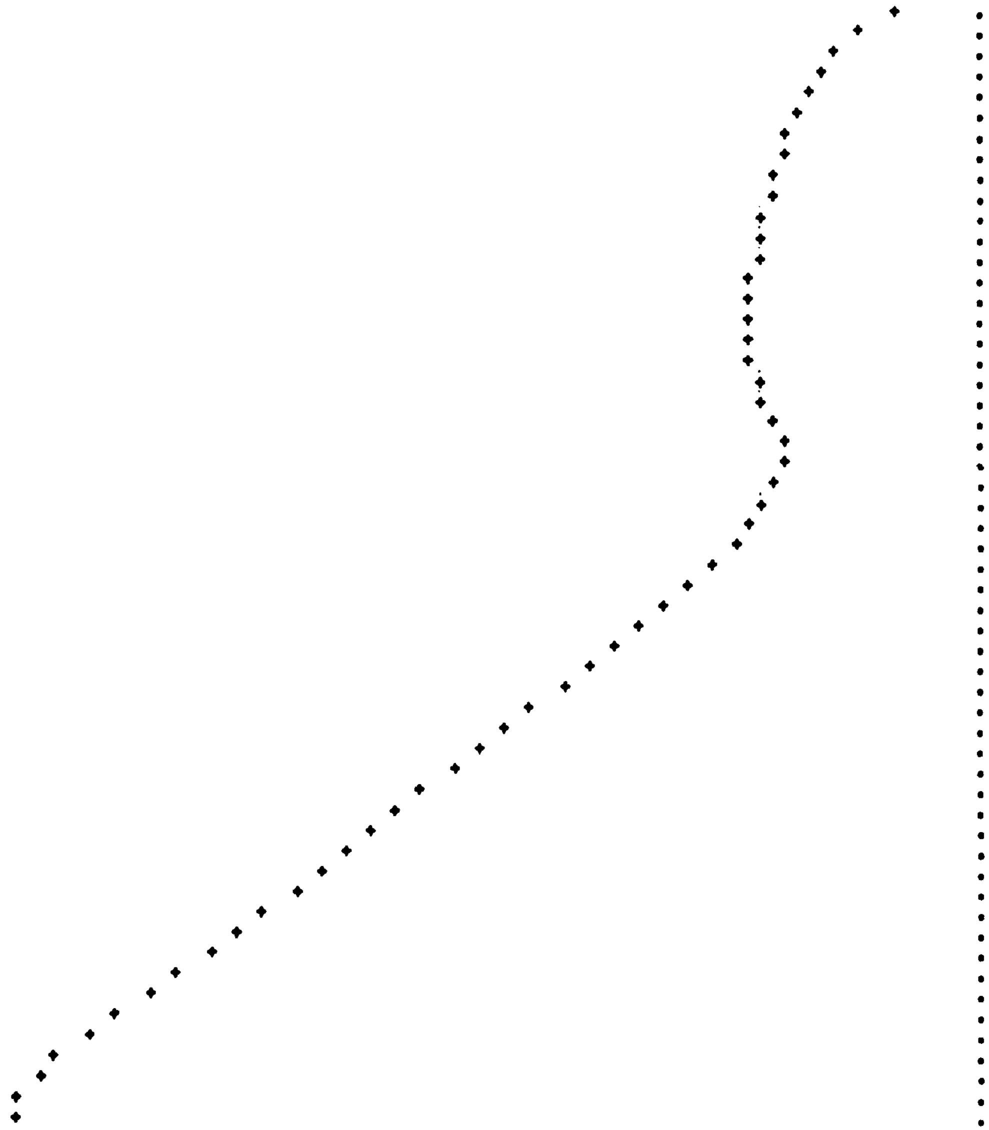
CD = .20349E-01

B.2 SAMPLE OUTPUT FOR FPE + CONMIN CODE

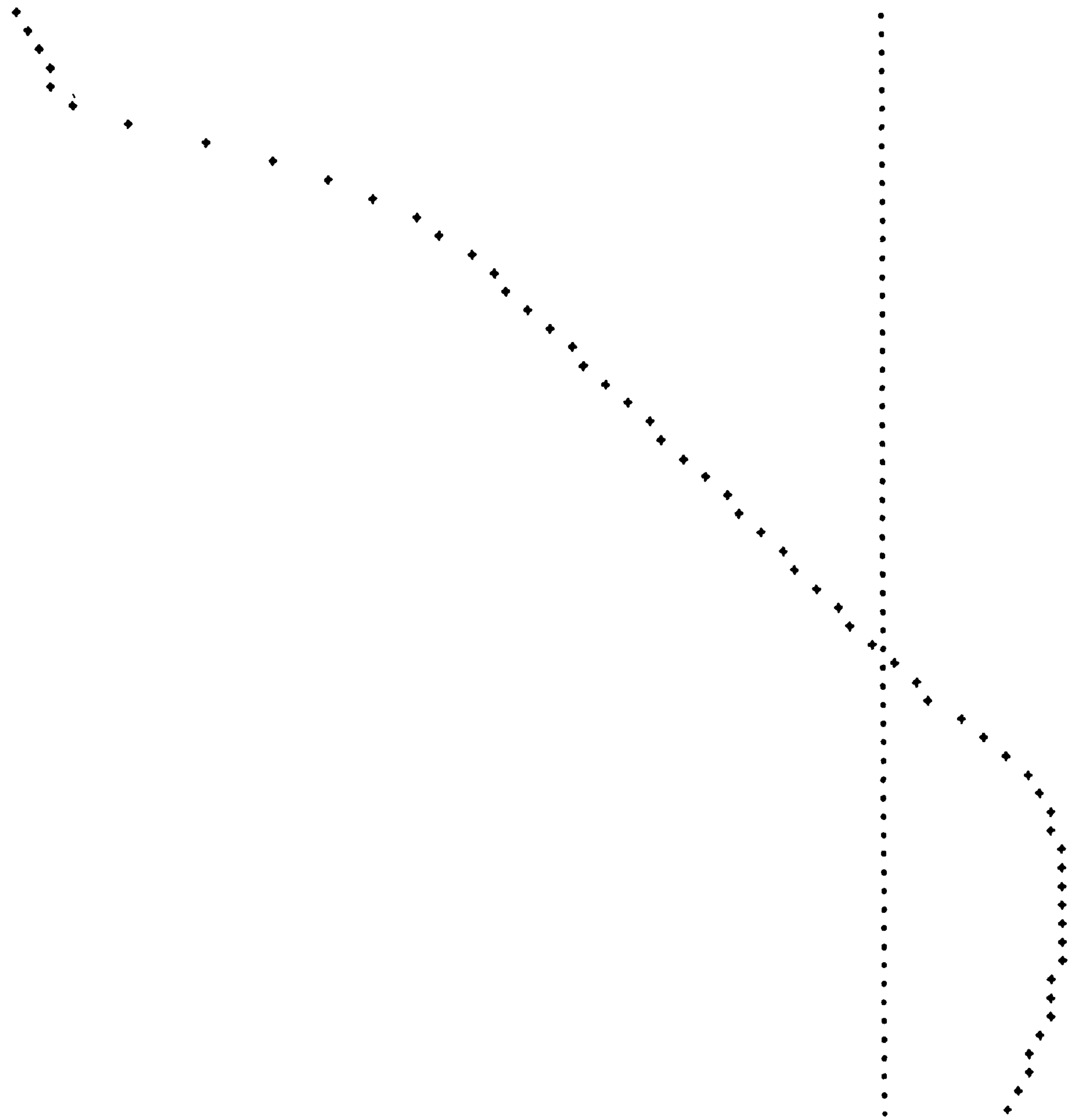
```
                                   FPE  GRID AND GEOMETRY INFORMATION
* * * * * ATWSEQ CONTROL FLAGS SET AS FOLLOWS * * * * *

             FESD       FFPE       OPTM       F2DBLS

              F          T          F          F

*** AIRFOIL ORDINATES INPUT FROM UNIT  5 ***


PROGRAM FLO22                                                         ANTONY JAMESON,COURANT INSTITUTE

THREE DIMENSIONAL WING ANALYSIS IN TRANSONIC FLOW USING SHEARED PARABOLIC COORDINATES

      INITIAL RUN IN FLO22 TEST

PLANFORM GEOMETRY REFERENCE VALUES


    SREF   =       1.89710
    CREF   =        .56230
    XREF   =       1.13300
    B/2    =       3.37400
    SWEEP1 =      37.93000
    SWEEP2 =      26.65800
    SWEEP  =      26.65800
    DIHED1 =       0.00000
    DIHED2 =       0.00000
    DIHED  =       0.00000
XSING =      .029592      YSING =     -.002565
XSING =      .029592      YSING =     -.002565
XSING =      .011846      YSING =     -.001265
XSING =      .007945      YSING =      .000148
```

CHORDWISE CELL DISTRIBUTION IN SQUARE ROOT PLANE AND MAPPED SURFACE COORDINATES AT CENTER LINE AND TIP

I	X	ROOT PROFILE
2	-1.8405	.0106
3	-1.4540	.0144
4	-1.2764	.0170
5	-1.1667	.0190
6	-1.0890	.0206
7	-1.0295	.0220
8	-.9814	.0231
9	-.9410	.0241
10	-.9062	.0250
11	-.8756	.0257
12	-.8480	.0263
13	-.8229	.0268
14	-.7997	.0272
15	-.7780	.0275
16	-.7576	.0277
17	-.7382	.0278
18	-.7195	.0276
19	-.7015	.0274
20	-.6841	.0269
21	-.6669	.0261
22	-.6501	.0250
23	-.6333	.0235
24	-.6167	.0236
25	-.6000	.0247
26	-.5833	.0263
27	-.5667	.0281
28	-.5500	.0302
29	-.5333	.0325
30	-.5167	.0351
31	-.5000	.0381
32	-.4833	.0412
33	-.4667	.0444
34	-.4500	.0476
35	-.4333	.0508
36	-.4167	.0542
37	-.4000	.0575
38	-.3833	.0608
39	-.3667	.0640
40	-.3500	.0673
41	-.3333	.0706
42	-.3167	.0737
43	-.3000	.0768
44	-.2833	.0799
45	-.2667	.0832
46	-.2500	.0866
47	-.2333	.0901
48	-.2167	.0937
49	-.2000	.0974
50	-.1833	.1011
51	-.1667	.1049
52	-.1500	.1086
53	-.1333	.1118
54	-.1167	.1143
55	-.1000	.1161
56	-.0833	.1168
57	[illegible]	[illegible]

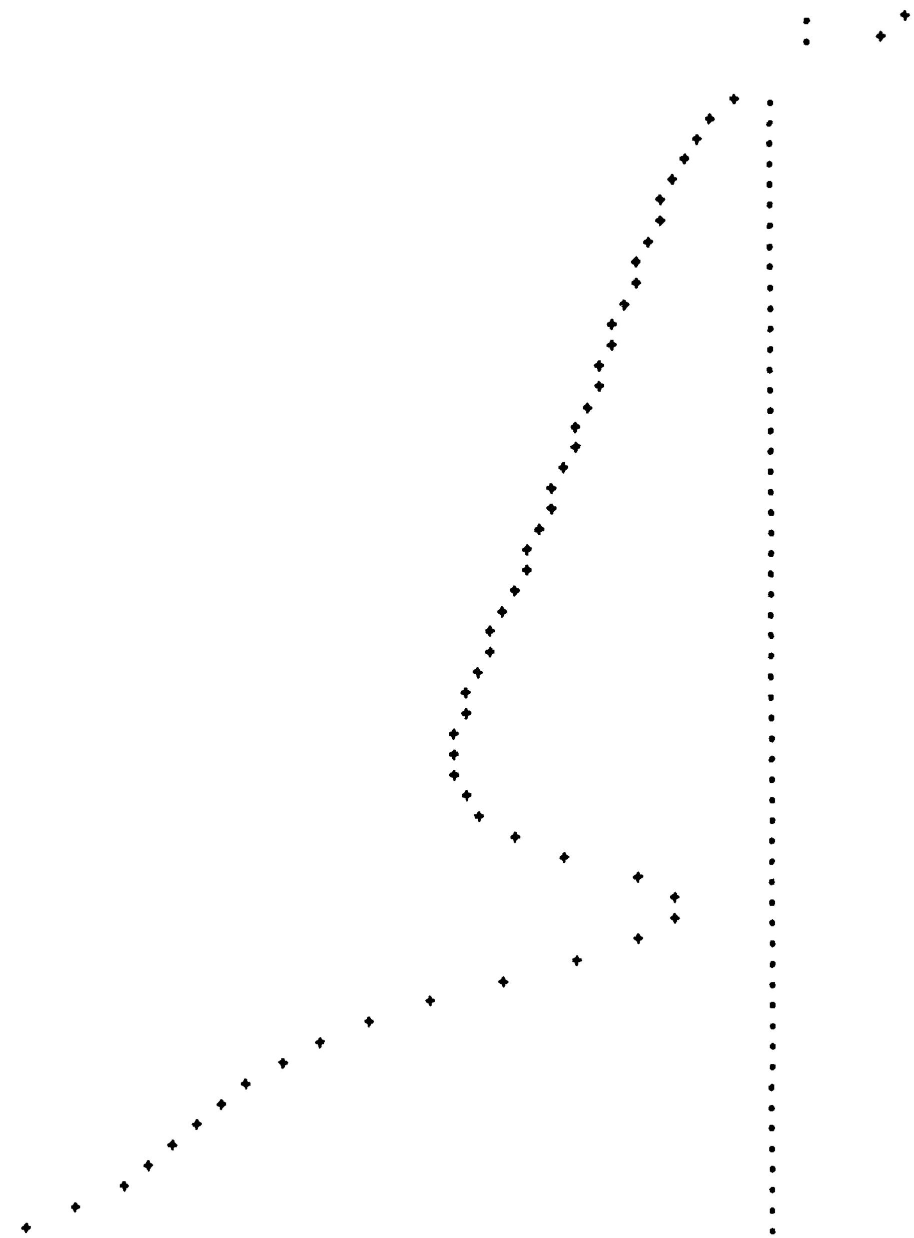


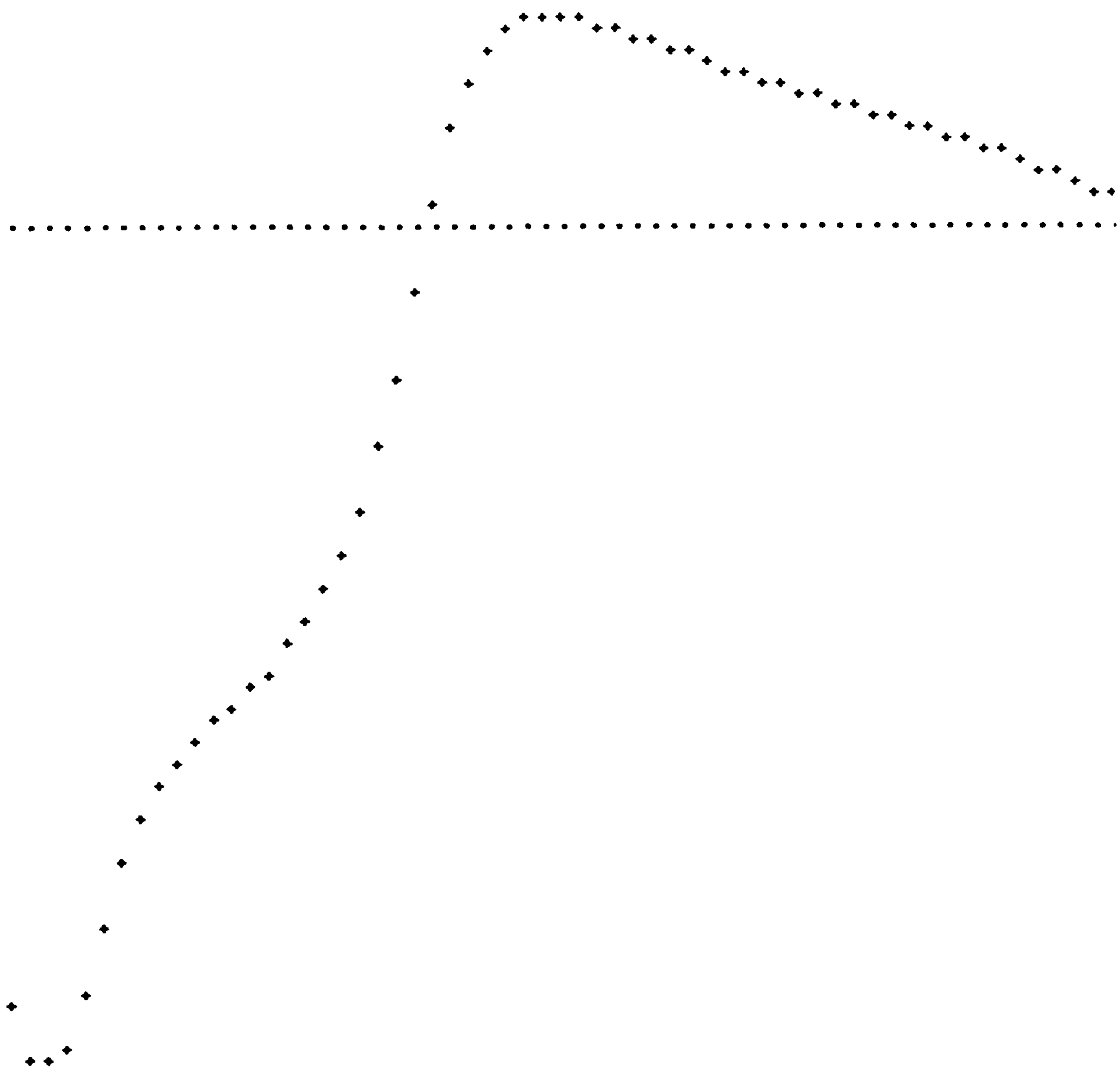
58	-.0500	..152
59	-.0333	.1137
60	-.0167	.1121
61	0.0000	.1109
62	.0167	.1105
63	.0333	.1084
64	.0500	.1010
65	.0667	.0908
66	.0833	.0812
67	.1000	.0735
68	.1167	.0675
69	.1333	.0628
70	.1500	.0588
71	.1667	.0554
72	.1833	.0523
73	.2000	.0495
74	.2167	.0469
75	.2333	.0444
76	.2500	.0419
77	.2667	.0393
78	.2833	.0368
79	.3000	.0342
80	.3167	.0316
81	.3333	.0290
82	.3500	.0264
83	.3667	.0238
84	.3833	.0212
85	.4000	.0187
86	.4167	.0162
87	.4333	.0137
88	.4500	.0113
89	.4667	.0089
90	.4833	.0064
91	.5000	.0040
92	.5167	.0015
93	.5333	-.0012
94	.5500	-.0039
95	.5667	-.0068
96	.5833	-.0098
97	.6000	-.0128
98	.6167	-.0159
99	.6333	-.0187
100	.6501	-.0204
101	.6669	-.0216
102	.6841	-.0225
103	.7015	-.0231
104	.7195	-.0235
105	.7382	-.0237
106	.7576	-.0238
107	.7780	-.0237
108	.7997	-.0235
109	.8229	-.0232
110	.8480	-.0228
111	.8756	-.0223
112	.9062	-.0217
113	.9410	-.0210
114	.9814	-.0201
115	1.0295	-.0191
116	1.0890	-.0179
117	1.1667	-.0164
[illegible]	[illegible]	[illegible]



119	1.4540	-.0124
120	1.8405	-.0090

I	X	TIP PROFILE
2	-1.8405	.0014
3	-1.4540	.0020
4	-1.2764	.0025
5	-1.1667	.0029
6	-1.0890	.0033
7	-1.0295	.0036
8	-.9814	.0039
9	-.9410	.0042
10	-.9062	.0045
11	-.8756	.0047
12	-.8480	.0050
13	-.8229	.0053
14	-.7997	.0055
15	-.7780	.0058
16	-.7576	.0060
17	-.7382	.0063
18	-.7195	.0065
19	-.7015	.0068
20	-.6841	.0070
21	-.6669	.0073
22	-.6501	.0076
23	-.6333	.0079
24	-.6167	.0082
25	-.6000	.0085
26	-.5833	.0088
27	-.5667	.0091
28	-.5500	.0095
29	-.5333	.0098
30	-.5167	.0101
31	-.5000	.0104
32	-.4833	.0106
33	-.4667	.0108
34	-.4500	.0109
35	-.4333	.0108
36	-.4167	.0105
37	-.4000	.0100
38	-.3833	.0089
39	-.3667	.0072
40	-.3500	.0045
41	-.3333	.0031
42	-.3167	.0032
43	-.3000	.0044
44	-.2833	.0066
45	-.2667	.0092
46	-.2500	.0117
47	-.2333	.0138
48	-.2167	.0155
49	-.2000	.0168
50	-.1833	.0179
51	-.1667	.0188
52	-.1500	.0196
53	-.1333	.0204
54	-.1167	.0213
55	-.1000	.0224
56	-.0833	.0237
57	-.0667	.0255





59	-.0333	.0299
60	-.0167	.0316
61	0.0000	.0318
62	.0167	.0315
63	.0333	.0294
64	.0500	.0266
65	.0667	.0243
66	.0833	.0227
67	.1000	.0215
68	.1167	.0205
69	.1333	.0197
70	.1500	.0190
71	.1667	.0184
72	.1833	.0177
73	.2000	.0169
74	.2167	.0161
75	.2333	.0150
76	.2500	.0138
77	.2667	.0124
78	.2833	.0107
79	.3000	.0085
80	.3167	.0058
81	.3333	.0024
82	.3500	-.0008
83	.3667	-.0037
84	.3833	-.0056
85	.4000	-.0067
86	.4167	-.0074
87	.4333	-.0078
88	.4500	-.0080
89	.4667	-.0080
90	.4833	-.0079
91	.5000	-.0078
92	.5167	-.0076
93	.5333	-.0074
94	.5500	-.0071
95	.5667	-.0069
96	.5833	-.0066
97	.6000	-.0064
98	.6167	-.0061
99	.6333	-.0059
100	.6501	-.0056
101	.6669	-.0054
102	.6841	-.0052
103	.7015	-.0049
104	.7195	-.0047
105	.7382	-.0045
106	.7576	-.0043
107	.7780	-.0041
108	.7997	-.0039
109	.8229	-.0037
110	.8480	-.0035
111	.8756	-.0033
112	.9062	-.0031
113	.9410	-.0028
114	.9814	-.0026
115	1.0295	-.0024
116	1.0890	-.0021
117	1.1667	-.0018
118	1.2764	-.0015
119	1.4540	-.0011

120	1.8405	-.0007

TE LOCATION	POWER LAW
.6250	.5000

NORMAL CELL DISTRIBUTION IN SQUARE ROOT PLANE

	Y
2	1.5212
3	1.0324
4	.8068
5	.6667
6	.5669
7	.4901
8	.4277
9	.3750
10	.3293
11	.2887
12	.2520
13	.2182
14	.1868
15	.1572
16	.1291
17	.1021
18	.0759
19	.0503
20	.0250
21	0.0000

SCALE FACTOR	POWER LAW
.5000	.5000

SPANWISE CELL DISTRIBUTION AND SINGULAR LINE

	Z	X SING	Y SING
3	0.0000	.0314	-.0027
4	.0417	.2000	-.0025
5	.0833	.3682	-.0021
6	.1250	.5357	-.0015
7	.1667	.6963	-.0010
8	.2083	.8439	-.0005
9	.2500	.9781	-.0002
10	.2917	1.1007	.0001
11	.3333	1.2139	.0002
12	.3750	1.3197	.0003
13	.4167	1.4202	.0003
14	.4583	1.5173	.0003
15	.5000	1.6132	.0002
16	.5417	1.7098	.0001
17	.5833	1.8092	.0001
18	.6250	1.9136	.0001
19	.6667	2.0239	.0001
20	.7096	2.1372	.0001
21	.7554	2.2585	.0001
22	.8071	2.3950	.0001
23	.8689	2.5585	.0001
24	.9498	2.7723	.0001
25	1.0717	3.0947	.0001
26	1.3204	3.7522	.0001

TIP LOCATION	POWER LAW
.6406	.5000

ITERATIVE SOLUTION

1.0000

NX	NY	NZ
120	20	24

FPE ITERATION CONVERGENCE INFORMATION

MACH NO	YAW	ANG OF ATTACK
.8000	0.0000	0.0000

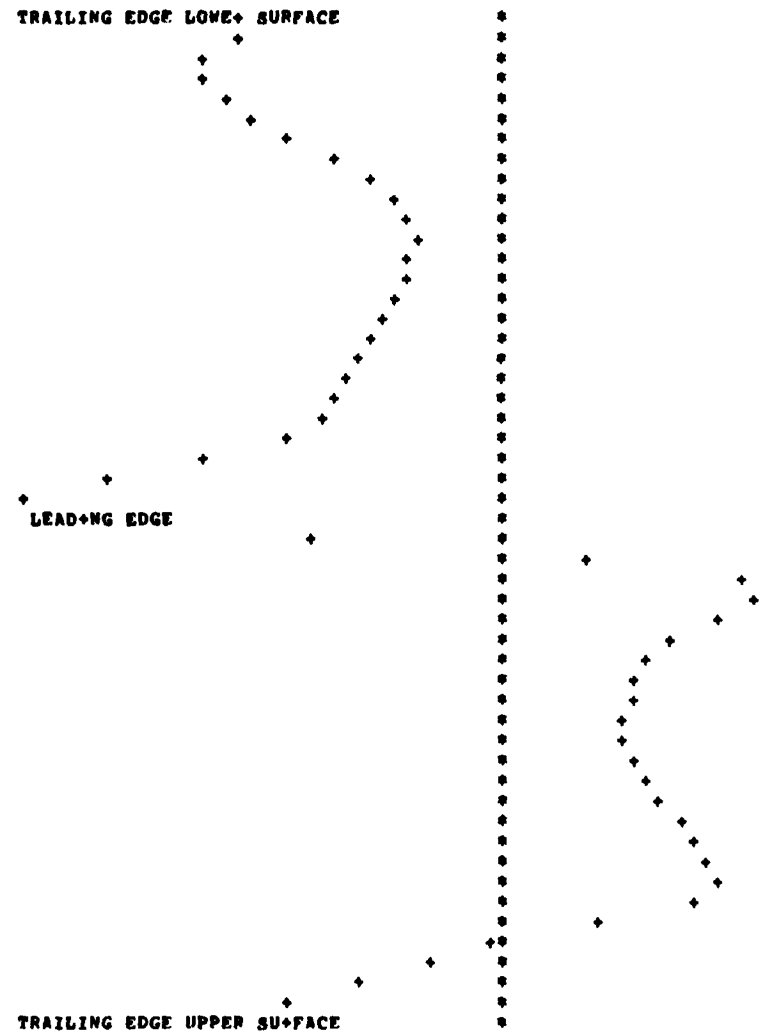
ITERATION	CORRECTION	I	J	K	RESIDUAL	I	J	K	CIRCULATN	REL FCT 1	REL FCT 2	REL FCT 3	BETA	SONIC PTS
1	.16075E-01	2	21	10	-.10087E-01	2	21	10	.03204	1.70000	1.00000	1.00000	.10000	1104
2	.92532E-02	2	20	10	-.12382E-01	2	20	10	.03200	1.70000	1.00000	1.00000	.10000	1117
3	.52280E-02	2	19	10	-.71140E-02	2	19	11	.03192	1.70000	1.00000	1.00000	.10000	1112
4	-.41899E-02	2	21	3	-.39509E-02	2	18	11	.03216	1.70000	1.00000	1.00000	.10000	1126
5	.32451E-02	2	21	3	-.22522E-02	2	19	3	.03226	1.70000	1.00000	1.00000	.10000	1138
6	-.27710E-02	2	21	3	-.17637E-02	2	18	3	.03233	1.70000	1.00000	1.00000	.10000	1122
7	.19817E-02	2	21	3	.13353E-02	120	20	4	.03239	1.70000	1.00000	1.00000	.10000	1146
8	-.17273E-02	2	21	3	.10839E-02	2	21	3	.03243	1.70000	1.00000	1.00000	.10000	1142
9	.11896E-02	2	21	3	.88739E-03	120	20	4	.03246	1.70000	1.00000	1.00000	.10000	1152
10	-.10981E-02	2	21	3	-.71979E-03	2	16	3	.03250	1.70000	1.00000	1.00000	.10000	1164
11	.73570E-03	2	21	3	.60468E-03	120	20	4	.03253	1.70000	1.00000	1.00000	.10000	1162
12	-.71015E-03	2	21	3	-.50564E-03	2	15	3	.03255	1.70000	1.00000	1.00000	.10000	1176
13	.45614E-03	2	21	3	-.45447E-03	2	15	3	.03258	1.70000	1.00000	1.00000	.10000	1172
14	-.46878E-03	2	21	3	-.39620E-03	2	15	3	.03260	1.70000	1.00000	1.00000	.10000	1183
15	.37201E-03	75	19	4	-.34834E-03	2	15	3	.03262	1.70000	1.00000	1.00000	.10000	1188
16	.34237E-03	74	20	4	-.31012E-03	2	14	3	.03264	1.70000	1.00000	1.00000	.10000	1194
17	.33743E-03	76	19	4	-.28365E-03	2	14	3	.03266	1.70000	1.00000	1.00000	.10000	1195
18	.27202E-03	77	18	4	-.25973E-03	2	14	3	.03268	1.70000	1.00000	1.00000	.10000	1201
19	.27563E-03	78	19	4	-.23901E-03	2	14	3	.03270	1.70000	1.00000	1.00000	.10000	1205
20	-.23416E-03	86	21	7	-.21758E-03	2	14	3	.03272	1.70000	1.00000	1.00000	.10000	1204
21	.22971E-03	81	19	4	-.20076E-03	2	14	3	.03274	1.70000	1.00000	1.00000	.10000	1210
22	.19514E-03	85	21	3	-.18682E-03	2	13	3	.03276	1.70000	1.00000	1.00000	.10000	1210
23	.19343E-03	83	19	4	-.17288E-03	2	13	3	.03278	1.70000	1.00000	1.00000	.10000	1218
24	.18341E-03	87	21	3	-.16094E-03	2	13	3	.03279	1.70000	1.00000	1.00000	.10000	1220
25	.19180E-03	86	20	3	-.14917E-03	2	13	3	.03281	1.70000	1.00000	1.00000	.10000	1227
26	.18336E-03	88	21	3	.14137E-03	120	14	3	.03283	1.70000	1.00000	1.00000	.10000	1229
27	.18534E-03	87	20	3	.13358E-03	120	14	3	.03285	1.70000	1.00000	1.00000	.10000	1233
28	.17206E-03	89	21	3	.12711E-03	120	14	3	.03286	1.70000	1.00000	1.00000	.10000	1235
29	.17247E-03	88	20	3	.12028E-03	120	14	3	.03288	1.70000	1.00000	1.00000	.10000	1237
30	.15732E-03	89	21	3	.11438E-03	120	14	3	.03290	1.70000	1.00000	1.00000	.10000	1236
31	.14679E-03	88	20	3	.10844E-03	120	14	3	.03291	1.70000	1.00000	1.00000	.10000	1243
32	.14213E-03	90	21	3	.10316E-03	120	14	3	.03293	1.70000	1.00000	1.00000	.10000	1244
33	.11866E-03	88	20	3	.98035E-04	120	14	3	.03295	1.70000	1.00000	1.00000	.10000	1252
34	.11981E-03	91	21	3	.93412E-04	120	14	3	.03296	1.70000	1.00000	1.00000	.10000	1253
35	.10110E-03	89	20	3	.88983E-04	120	14	3	.03298	1.70000	1.00000	1.00000	.10000	1259
36	.97282E-04	91	21	3	.84943E-04	120	14	3	.03299	1.70000	1.00000	1.00000	.10000	1263
37	.81224E-04	89	20	3	.81256E-04	120	13	3	.03301	1.70000	1.00000	1.00000	.10000	1266
38	.77251E-04	91	21	3	.77747E-04	120	13	3	.03303	1.70000	1.00000	1.00000	.10000	1268
39	-.73028E-04	120	12	3	.74546E-04	120	13	3	.03304	1.70000	1.00000	1.00000	.10000	1271
40	-.70246E-04	120	12	3	.71439E-04	120	13	3	.03306	1.70000	1.00000	1.00000	.10000	1271
41	-.67775E-04	120	11	3	.68607E-04	120	13	3	.03307	1.70000	1.00000	1.00000	.10000	1272
42	-.65416E-04	120	11	3	.65848E-04	120	13	3	.03309	1.70000	1.00000	1.00000	.10000	1272
43	-.63180E-04	120	11	3	.63327E-04	120	13	3	.03310	1.70000	1.00000	1.00000	.10000	1272
44	-.61027E-04	120	11	3	.60872E-04	120	13	3	.03312	1.70000	1.00000	1.00000	.10000	1273
45	-.58985E-04	120	11	3	.58620E-04	120	13	3	.03313	1.70000	1.00000	1.00000	.10000	1274
46	-.57023E-04	120	11	3	.56431E-04	120	13	3	.03315	1.70000	1.00000	1.00000	.10000	1275
47	-.55159E-04	120	11	3	.54411E-04	120	13	3	.03316	1.70000	1.00000	1.00000	.10000	1279
48	-.53370E-04	120	11	3	.52454E-04	120	13	3	.03318	1.70000	1.00000	1.00000	.10000	1280
49	-.51668E-04	120	11	3	.50635E-04	120	13	3	.03319	1.70000	1.00000	1.00000	.10000	1282
50	-.50067E-04	120	10	3	.48879E-04	120	13	3	.03320	1.70000	1.00000	1.00000	.10000	1283

SECTION CHARACTERISTICS K = 15 FPE CONVERGED SOLUTION INFORMATION

MACH NO	YAW	ANG OF ATTACH	SPAN STATION	CL	CD	CM
.8000	0.0000	0.0000	.7805	.7942	.0092	-.1683

PLOT OF CP AT EQUAL INTERVALS IN THE MAPPED PLANE
CP* = -.435 CHORD = .4267

	X/C	Y/C	MACHL	CP	U	V	W
	1.0000	-.0395	-.6590	.3100	.8276	-.1165	.0743
37	.9952	-.0385	-.6554	.3179	.8231	-.1178	.0756
38	.9148	-.0312	-.6173	.3991	.7846	-.0363	.0851
39	.8378	-.0305	-.6194	.3947	.7880	.0120	.0829
40	.7641	-.0332	-.6391	.3527	.8107	.0520	.0751
41	.6937	-.0396	-.6746	.2762	.8506	.0892	.0616
42	.6266	-.0477	-.7247	.1667	.9078	.1087	.0422
43	.5628	-.0554	-.7801	.0442	.9718	.1066	.0204
44	.5024	-.0614	-.8295	-.0654	1.0292	.0834	.0008
45	.4454	-.0650	-.8638	-.1410	1.0685	.0493	-.0125
46	.3919	-.0666	-.8818	-.1805	1.0887	.0152	-.0191
47	.3418	-.0665	-.8876	-.1932	1.0949	-.0158	-.0205
48	.2952	-.0653	-.8849	-.1874	1.0914	-.0438	-.0183
49	.2521	-.0630	-.8765	-.1689	1.0811	-.0686	-.0135
50	.2124	-.0601	-.8648	-.1433	1.0670	-.0907	-.0070
51	.1761	-.0566	-.8510	-.1128	1.0499	-.1117	.0006
52	.1432	-.0527	-.8354	-.0783	1.0305	-.1319	.0093
53	.1137	-.0485	-.8190	-.0421	1.0094	-.1522	.0186
54	.0876	-.0442	-.8024	-.0054	.9868	-.1754	.0286
55	.0648	-.0397	-.7856	.0319	.9617	-.2046	.0398
56	.0452	-.0349	-.7632	.0815	.9240	-.2500	.0566
57	.0288	-.0296	-.7155	.1868	.8418	-.3182	.0930
58	.0159	-.0233	-.6171	.3995	.6738	-.3767	.1668
59	.0068	-.0159	-.4658	.7003	.4248	-.3317	.2757
60	.0015	-.0077	-.3286	.9252	.1987	-.0815	.3744
61	0.0000	.0005	.4279	.7680	.1796	.3645	.3823
62	.0020	.0085	.7538	.1023	.5234	.7563	.2310
63	.0085	.0154	1.1297	-.6965	1.0778	.7937	-.0130
64	.0186	.0205	1.3691	-1.1157	1.4210	.5973	-.1644
65	.0317	.0248	1.4012	-1.1647	1.5024	.4325	-.2007
66	.0479	.0286	1.3312	-1.0555	1.4709	.3277	-.1875
67	.0672	.0324	1.2605	-.9369	1.4243	.2617	-.1674
68	.0898	.0360	1.2207	-.8666	1.3973	.2160	-.1557
69	.1158	.0395	1.2000	-.8290	1.3840	.1800	-.1498
70	.1451	.0429	1.1875	-.8059	1.3763	.1513	-.1463
71	.1778	.0460	1.1827	-.7970	1.3745	.1260	-.1453
72	.2140	.0489	1.1864	-.8040	1.3798	.1023	-.1472
73	.2535	.0513	1.1978	-.8250	1.3913	.0780	-.1518
74	.2965	.0532	1.2154	-.8570	1.4078	.0529	-.1585
75	.3430	.0545	1.2384	-.8982	1.4283	.0254	-.1668
76	.3929	.0548	1.2648	-.9443	1.4509	-.0052	-.1758
77	.4462	.0540	1.2934	-.9931	1.4743	-.0375	-.1851
78	.5030	.0519	1.3228	-1.0418	1.4972	-.0722	-.1943
79	.5632	.0484	1.3409	-1.0710	1.5096	-.1073	-.2005
80	.6268	.0434	1.2933	-.9929	1.4677	-.1373	-.1896
81	.6938	.0366	1.1334	-.7037	1.3248	-.1580	-.1453
82	.7643	.0275	.9920	-.4177	1.1853	-.1844	-.1011
83	.8380	.0147	.9066	-.2348	1.0921	-.2150	-.0720
84	.9151	-.0017	.8153	-.0340	.9926	-.2170	-.0429
85	.9955	-.0193	.7236	.1690	.8935	-.1920	-.0145
	1.0000	-.0202	.7231	.1701	.8937	-.1868	-.0146



WING CHARACTERISTICS

MACH NO	YAW	ANG OF ATTACK			
.8000	0.0000	0.0000			
CL	CD FORM	CD FRICTION	CD	L/D FORM	L/D
.6352	.0221	.0100	.0321	28.7883	19.8099
CM PITCH	CM ROLL	CM YAW			
-.2281	1.7908	.0291			

SECTION COEFFICIENTS

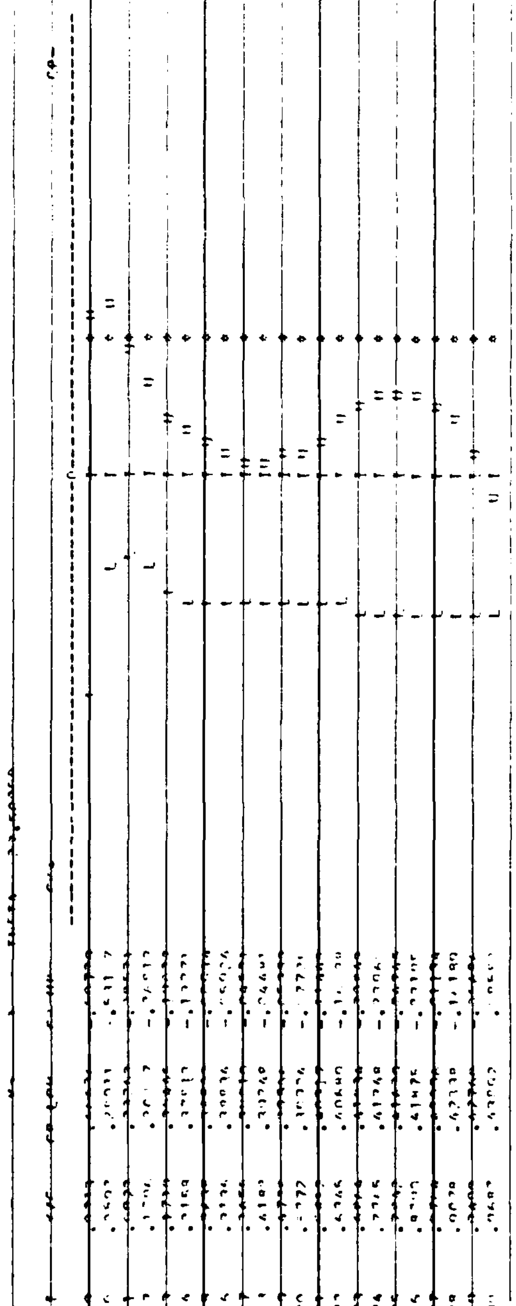
I	Z	CL	CDI	CM	CDS
1	.109721	.349173	.002253	.613164	.070512
2	.329163	.392811	.002604	.791674	.028565
3	.548604	.448062	.003162	1.031397	.013070
4	.768046	.528210	.004185	1.401722	.007461
5	.987488	.612152	.005368	1.838970	.008190
6	1.206930	.665221	.006176	2.183644	.011397
7	1.426371	.702304	.006812	2.463515	.012881
8	1.645813	.730936	.007326	2.697486	.013689
9	1.865255	.764734	.008295	2.975406	.010245
10	2.084696	.796561	.009648	3.252156	.007477
11	2.304138	.809695	.010870	3.419261	.004827
12	2.523580	.810617	.012381	3.517280	.000254
13	2.743022	.795584	.014531	3.518602	-.006845
14	2.962463	.753988	.018101	3.340024	-.017500
15	3.181905	.653957	.027570	2.721940	-.035711
16	3.401528	.287296	.035120	.024433	-.036228
17	3.624221	.001410	.023780	-2.068096	-.023716
18	3.857825	.000283	.010259	-2.006240	-.010252
19	4.114610	.000549	.006115	-1.926387	-.006113
20	4.413453	.000965	.003854	-1.831381	-.003854
21	4.789268	.001519	.002399	-1.711456	-.002399
22	5.323295	.002250	.001369	-1.550439	-.001369

CL	CDI	CDS	CDT	CDFORM
.651751	.011689	.011449	.023138	.022064

WING COEFFICIENTS FROM CONTROL VOLUME INT.

CL = .65175
CDI = .01169
CM = .70798
CDS = .01145
CDT = .02314
MO = .80000
ALF = 0.00000

B.3 TYPICAL WING AND NACELLE PRESSURE DISTRIBUTIONS FROM WING-PYLON-NACELLE CODE

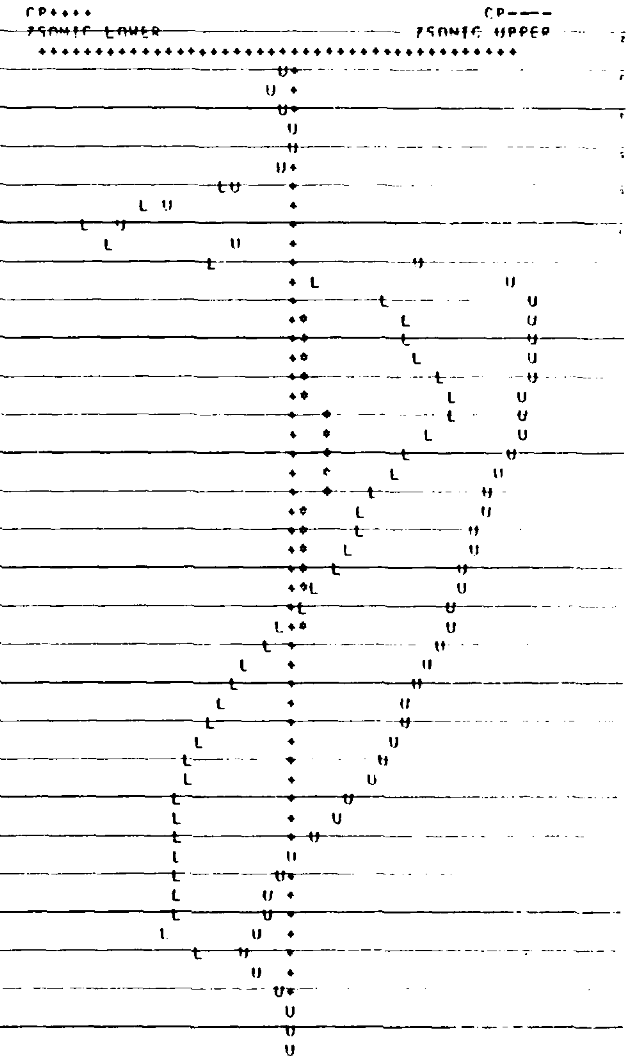


THETA = [illegible]

I	X/C	CP LOW	CP UP
[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	-.10712
[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	.41527	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
28	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

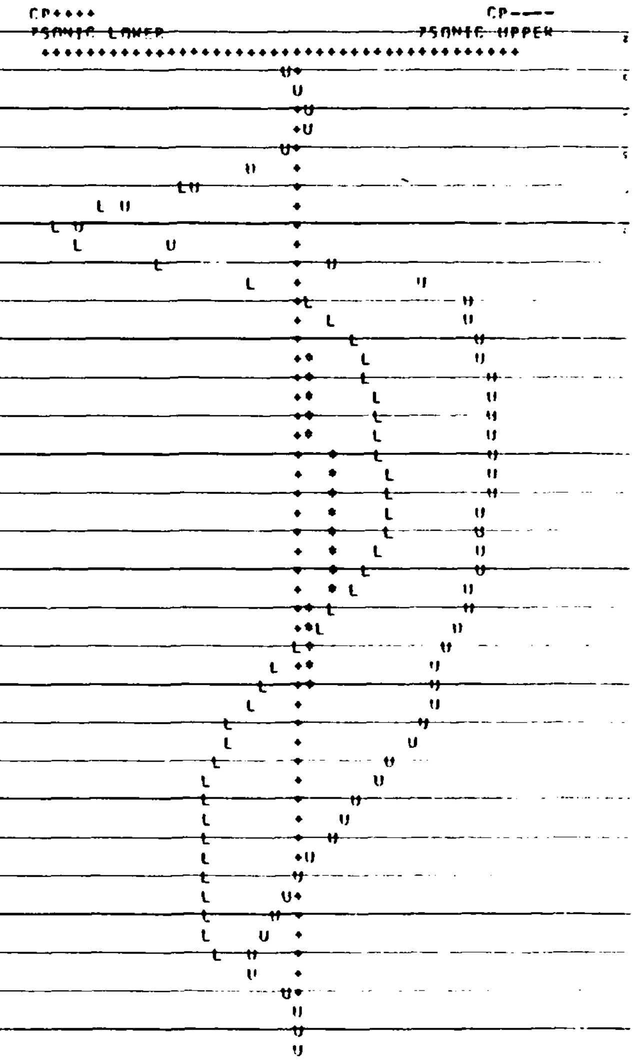
ETA/SSPAN = .2671

J	X/C	CPU	CPL	MU	ML	ZSONICU	ZSONICL
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	-1.6274[illegible]	.26081	.06175	.769	.769	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	-.71368	-.00376	-.00361	.802	.802	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	-.33633	.33197	.3605[illegible]	.734	.797	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	-.01779	.41347	.40144	.552	.491	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	.00759	.13615	.58440	.603	.406	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	.[illegible]235	-.70231	-.22444	1.100	.943	.041	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.041	[illegible]
15	.06909	-.80437	-.31595	1.137	.957	.157	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.157	[illegible]
17	.11656	-.74250	-.41217	1.173	.987	.157	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.157	[illegible]
19	.16998	-.76564	-.52762	1.123	1.032	.157	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.367	[illegible]
21	.22912	-.73742	-.46001	1.113	.900	.367	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.367	[illegible]
23	.30933	-.68325	-.31879	1.[illegible]73	.94[illegible]	.367	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.367	[illegible]
25	.35631	-.62570	-.24252	1.071	.91[illegible]	.157	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.157	[illegible]
27	.47563	-.58865	-.17531	1.257	.89[illegible]	.157	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.157	[illegible]
29	.40708	-.56625	-.[illegible]9547	1.046	.947	.157	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.157	[illegible]
31	.54037	-.51119	.02553	1.[illegible]27	.787	.157	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.041	[illegible]
33	.63600	-.44700	.13208	1.[illegible]02	.727	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
35	.60065	-.30060	.23[illegible]84	.979	.663	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
37	.74041	-.27884	.20765	.952	.625	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39	.81670	-.24593	.35[illegible]60	.916	.50[illegible]	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
41	.96021	-.13353	.27540	.865	.579	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
43	.91675	-.01643	.30445	.803	.573	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	.05807	.04200	.30336	.763	.573	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
47	.99039	.11555	.20542	.730	.565	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
49	1.07071	.11907	.1205[illegible]	.737	.733	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
51	1.57634	-.01687	-.01670	.903	.803	0.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
53	3.40302	.00317	.00315	.790	.733	0.000	0.000



ETA/SSPAN = .4100

J	X/C	CPU	CPL	MU	ML	ZSONICU	ZSONICL
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	-1.62261	.01307	.01308	.793	.793	0.000	0.000
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	-.71368	-.02813	-.02916	.814	.816	0.000	0.000
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	-.20673	.16116	.16549	.714	.711	0.000	0.000
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	-.01728	.65563	.73800	.328	.292	0.000	0.000
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	.00353	.44874	.94337	.519	.232	0.000	0.000
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	.02035	-.47453	.16910	1.213	.702	0.000	0.000
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	.06098	-.67105	-.14536	[illegible]	.871	.041	0.000
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	.11155	-.70736	-.25330	1.102	.922	.157	0.000
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	.16988	-.72872	-.29628	1.110	.939	.157	0.000
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	.22862	-.72916	-.31988	1.113	.948	.157	0.000
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	.29233	-.72543	-.33146	1.192	.954	.367	0.000
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	.35631	-.71521	-.33524	1.195	.955	.367	0.000
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	.42563	-.69060	-.30639	1.190	.943	.367	0.000
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	.49798	-.66065	-.21092	1.088	.901	.367	0.000
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	.56937	-.60615	-.07075	1.164	.835	.157	0.000
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
33	.63006	-.53016	.07228	1.138	.762	.157	0.000
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
35	.70065	-.50567	.19412	1.025	.695	.041	0.000
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
37	.76601	-.42553	.27761	[illegible]	.642	0.000	0.000
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39	.83170	-.30301	.33073	.943	.600	0.000	0.000
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
41	.86921	-.17443	.35933	.906	.593	0.000	0.000
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
43	.91675	-.05681	.36482	.828	.586	0.000	0.000
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	.95807	.03072	.35456	.790	.593	0.000	0.000
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
47	.99033	.17855	.24920	.732	.597	0.000	0.000
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
49	1.02671	.15883	.16606	.715	.711	0.000	0.000
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
51	1.57634	.01231	.01236	.794	.796	0.000	0.000
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
53	3.40[illegible]	.00001	[illegible]	[illegible]	[illegible]	0.000	0.000



B.4 TWODBL OUTPUT REQUIRED TO RUN LINKING CODES

PRINCIPAL BOUNDARY LAYER INFORMATION

INSTABILITY DOES NOT OCCUR

TRANSITION OCCURS AT STATION 5

LAMINAR SEPARATION DOES NOT OCCUR

TURBULENT SEPARATION DOES NOT OCCUR

LAMINAR BOUNDARY LAYER - STATIONS 1 TO 4

TURBULENT BOUNDARY LAYER - STATIONS 5 TO 33

I	X	X/C	CF	FORMI	FORM	THET	DELSR	DELTA	DELSR/C
1	0.00000	0.000000	0.000000	2.5872	3.1911	.000005	.000016	.000048	.000096
2	.00040	.002410	.012369	2.5163	3.1078	.000003	.000010	.000028	.000060
3	.00160	.009610	.006752	2.5414	3.1374	.000006	.000019	.000055	.000116
4	.00359	.021530	.004987	2.5536	3.1517	.000008	.000026	.000074	.000154
5	.00634	.038060	.004260	1.5629	1.9197	.000017	.000032	.000148	.000195
6	.00984	.059040	.004577	1.4646	1.8627	.000021	.000040	.000210	.000238
7	.01404	.084270	.004272	1.4550	1.8901	.000028	.000052	.000283	.000315
8	.01891	.113490	.004009	1.4476	1.9054	.000036	.000068	.000372	.000409
9	.02440	.146450	.003736	1.4404	1.9110	.000045	.000086	.000477	.000516
10	.03045	.182800	.003617	1.4343	1.9104	.000055	.000106	.000594	.000636
11	.03702	.222210	.003454	1.4295	1.9050	.000067	.000128	.000722	.000766
12	.04403	.264300	.003326	1.4266	1.8971	.000080	.000151	.000859	.000907
13	.05142	.308660	.003193	1.4266	1.8883	.000094	.000177	.001005	.001061
14	.05912	.354860	.003052	1.4314	1.8794	.000110	.000206	.001160	.001236
15	.06705	.402450	.002887	1.4436	1.8722	.000129	.000241	.001326	.001444
16	.07513	.450990	.002687	1.4666	1.8694	.000152	.000285	.001505	.001710
17	.08330	.500000	.002448	1.5027	1.8750	.000183	.000344	.001712	.002063
18	.09147	.549010	.002178	1.5529	1.8933	.000223	.000423	.001952	.002538
19	.09955	.597550	.001891	1.6185	1.9287	.000274	.000529	.002238	.003173
20	.10740	.645140	.001597	1.7016	1.9851	.000337	.000669	.002577	.004017
21	.11518	.691340	.001323	1.7980	2.0595	.000411	.000847	.002970	.005084
22	.12257	.735700	.001116	1.8859	2.1301	.000490	.001043	.003398	.006261
23	.12958	.777790	.001022	1.9259	2.1555	.000560	.001206	.003811	.007239
24	.13615	.817200	.001077	1.8829	2.0989	.000605	.001269	.004144	.007617
25	.14220	.853550	.001248	1.7853	1.9909	.000619	.001233	.004373	.007400
26	.14769	.886510	.001480	1.5776	1.8782	.000609	.001144	.004520	.006866
27	.15256	.915730	.001727	1.5830	1.7827	.000584	.001041	.004613	.006249
28	.15676	.940960	.001940	1.5137	1.7148	.000558	.000956	.004678	.005738
29	.16026	.961940	.002087	1.4703	1.6736	.000538	.000900	.004730	.005405
30	.16301	.978470	.002149	1.4524	1.6574	.000532	.000881	.004778	.005290
31	.16500	.990390	.002164	1.4474	1.6514	.000534	.000882	.004823	.005293
32	.16620	.997590	.002132	1.4540	1.6563	.000544	.000901	.004865	.005411
33	.16660	1.000000	.002064	1.4726	1.6718	.000560	.000936	.004896	.005618

APPENDIX C

ESD SUBROUTINE DESCRIPTION

ATWSEQ	Main program for both the ESD and the FPE code.
CONIN	Input routine for CONMIN data
CPDESD	Computes the objective function and constraints when optimization is selected.
DBNDY	Computes value of potential on the downstream boundary
ESDCON	Cycles CONMIN with the ESD code when optimization is selected.
ESDDRV	Sequencing routine for the ESD code
FARBDY	Interpolates potential on exterior-interior mesh boundaries
GCALC	Transfers updated values of circulation to two-dimensional array
IC	Calculates coefficients for extrapolation formulas used to find the jump in potential at the wing trailing edge
INPUT	Main input routine for ESD data
INTERP	Interpolates previously stored solution for use as initial guess
MESH	Generates stretched x, y or z grids
MESHIN	Performs interpolation searches and stores mesh index locations

MODWNG	Perturbs wing geometry when optimization is selected.
OUTP	Printed output routine
PCINT	Interpolates potentials onto coarse mesh
PFINT	Interpolates potentials onto fine mesh
SECTIN	Input routine for airfoil section coordinates
SETUP	Computes planform parameters and computational grid for fine inner mesh
SETUPX	Computes rectangular coarse exterior mesh and planform geometry
SIMP	Simpson's rule numerical integration routine used to compute flow parameters
SLOPY	Computes wing surface slopes
SMTH	Smooths input section ordinates
SOLVE	Performs SLR solution for inner grid
SOLVEX	Performs SLR solution for outer grid
SPLN1	Continuous derivative interpolation routines
STORE	Stores value of potential jump in a single dimension array
TCOEF	Computes finite difference equation coefficients on interior mesh

TCOEFX	Computes finite difference coefficients for coarse exterior mesh
WINGCO	Generates wing boundary conditions
WNGBDY	Computes potential at wing surface by interpolation from fine mesh solution.

APPENDIX D

FPE SUBROUTINE DESCRIPTION

ATWSEQ	Main program for both ESD and FPE
BLKDAT	Block data routine
CONIN	CONMIN input routine
COORD	Sets up stretched parabolic and spanwise coordinates
CPDES	Computes objective function and constraints when optimization is selected
CPUVW	Plots C_p at equal intervals in the mapped plane
CVOL	Integrates lift, induced drag, pitching moment and shock drag by control volume integration
DINT	Combines integrand with elemental area for control volume integration
ESTIM	Computes initial estimate of reduced potential
F	Function that defines integrand for control volume integration
FLOW	Calculates x, y, z coordinates, u, v, w velocity components, C_p, and density ratio at grid points
FORCE	Calculates section force coefficients
FPECON	Sequences CONMIN with the FPE code
FPEDRV	Driver routine for FPE code

GEOM	Defines geometry of the wing
GRAPH	CALCOMP plot routine for section pressure distributions
INPUT	Inputs FPE data
INTPL	Taylor series interpolation routine
MDWFPE	Perturbs wing geometry when optimization is selected
MIXFLO	Solves equations for mixed subsonic and supersonic flow
PPXY	Prints and plots mesh x, y values
PRTMSH	Prints description of computational mesh
PRTPLT	Sequencing routine for printed and plotted output
PXPYP	Prints values of XP and YP
RDGSO	Transfers current values of potential to temporary array
REFIN	Performs mesh halving
REFSMO	Smooths refined mesh
RESTRT	Reads restart data for start from a stored solution
SAVE	Saves data on mass storage for future restart
SECTIN	Inputs control station airfoil section coordinates
SINGL	Generates singular line for square root transformation
SMOO	Smooths potential values

SOLVE	Sequencing routine for SCR solution
SPLIF	Spline fit routine
STR2BL	Outputs data for TWODBL program
SURF	Interpolates mapped wing surface at mesh points
THREED	Generates three-dimensional plots
TOTFOR	Calculates total force coefficients
TRI	Computes areas and normal vectors for triangular elements used in control volume integration
VELO	Computes surface velocity
WRTSGO	Transfers potential values from temporary storage
XYSING	Computes coordinates of singular point at each span station
YSWEEP	Performs row relaxation

APPENDIX E

TWODBL SUBROUTINE DESCRIPTION

CURVFT	Evaluates a polynomial f(x,y) for a given set of coefficients
FUNCT	FUNCT expresses the functional relationship between displacement thickness δ^* and correlation number
GRADNT	Computes the gradient of a function with respect to x
INPUT	Reads and prints all input data
INT1	Computes integrand used in first call of SIMPS1 integration routine
INT2	Computes integrand used in second call of SIMPS1 integration routine
LAMNAR	Solves the laminar boundary-layer equation, computes laminar-boundary-layer parameters, checks for instability and transition to turbulent flow and computes initial values for turbulent boundary layer when transition occurs.
LGRNGE	Performs four point Lagrange interpolation
PRECAL	Computes initial parameters required for solution of boundary layer equations
PROFIL	Prints all the principal boundary-layer parameters computed by LAMNAR and TURBLN, and calculates and prints the laminar and turbulent velocity profiles

ROOT	Locates a root for a given function in a given interval.
RUNKUT	Solves the coupled ordinary differential equations of the turbulent boundary layer using fourth-order Runga-Kutta method.
SIMPS1	Performs numerical integration by a modified Simpson's rule method
SMOOTH	SMOOTH is a simple-data smoothing array
SPLINE	Cubic spline interpolation routine
TURBLN	Solves the turbulent-boundary layer equations and computes the turbulent-boundary layer parameters

APPENDIX F

WING-PYLON/NACELLE PROGRAM SUBROUTINE DESCRIPTION*

AXIS	Computes finite difference terms along nacelle axis
CUTOUT	Aborts program when error condition is detected
GRID	Generates finite difference mesh for nacelle
GRIDGEN	Generates a wing grid tailored to the pylon/nacelle combination
MAIN	Computes transonic flow about wing
METRIC	Computes metric coefficients for finite difference equations in nacelle solution
NACELLE	Computes transonic flow about nacelle
OUTNAC	Outputs nacelle potential solution to Unit 9
PYLCO	Computes pylon first and second derivatives
PYLON	Computes special diagonal and RHS difference expressions for wing-pylon solution.
SETIN	Computes coefficients of the difference equations for tridiagonal solver in nacelle solution.
SHAZ	Transfers wing and nacelle boundary conditions during wing/nacelle solution cycle

* See Appendix C for description of subroutines used by ESD wing code but not described here.

SLOPPY	Sets up computation of wing surface slopes
TALA	Main program for wing-pylon/nacelle code
TRID	Tridiagonal equation solver

APPENDIX G

LOGICAL UNITS REFERENCED IN PROGRAMS

TAPE4	Input unit for stored solution data used to restart FPE program
TAPE5	Card reader logical unit (all programs)
TAPE6	Printer logical unit (all programs)
TAPE7	Output unit for solution data used to restart subsequent runs of the FPE program
	Input unit in TWODBL program for data generated in design and analysis programs
	Input unit in LINKUP and LINKDN for data generated by TWODBL
TAPE8	Input unit for airfoil section data when AFIN=F in ESD and FPE programs
	Input unit for solution data used to restart nacelle solution in wing-pylon/nacelle code
	Output unit for wing ordinates generated by LINKUP and LINKDN
	Output unit for TWODBL data used in LINKUP and LINKDN
TAPE9	Output unit for nacelle solution data used to restart subsequent runs of the wing-pylon/nacelle code
TAPE10	Input unit for stored wing solution data used to restart the ESD and wing-pylon/nacelle codes

TAPE11 Output unit for wing solution data to be used to restart subsequent runs of the ESD and wing-pylon/nacelle codes.

TAPE12 Output unit in ESD and FPE codes for data to be used in TWODBL program

Input unit in wing-pylon/nacelle code for airfoil section data when AFIN=F.

TAPE14 ESD plot data output unit

*U.S.Government Printing Office: 1981 — 559-005/4025

DAT

FILM

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